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FINAL REPORT

AN EVALUATION OF REACTION WHEEL EMITTED VIBRATIONS FOR SPACE TELESCOPE

PREPARED FOR

NASA/MSFC
HUNTSVILLE, ALABAMA
CONTRACT NO. NAS8-31998
MARCH 1977

SPERRY
FLIGHT SYSTEMS

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SPERRY FLIGHT SYSTEMS IS A DIVISION OF SPERRY RAND CORPORATION

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INTRODUCTION AND BACKGROUND

SECTION 1.0

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

This final report presents the results of a development program conducted by Sperry Flight Systems (SFS) to characterize the emitted vibrations of the Space Telescope Reaction Wheel Assembly (ST RWA).

1.2 BACKGROUND

The Space Telescope is to be a free-flying, autonomous, astronomical observatory. It will employ a 2.4 meter diffraction-limited primary mirror and require a pointing stability of .005 arc-second rms. Reactions wheels will be used as the momentum exchange actuator. Reaction wheels present a problem when operating over a range of speeds since they generate emitted vibration over a corresponding range of frequencies. If any of the frequencies excite structural or appendage resonances, the probability of achieving the required pointing stability goal is jeopardized.

To further the understanding of RWA emitted vibration characteristics, SFS conducted a program to evaluate reaction wheel-emitted vibration for the ST ("An Evaluation of Reaction Wheel Emitted Vibration for Large Space Telescope," prepared for NASA/MSFC, January 1976, SFS Publication No. 71-0824-00-00). This study characterized emitted force and momentum vibration data in three axes for three existing SFS assemblies. A 9.5 N-m-s (7 ft-lb-sec) (FLTSATCOM) and a 40.7 N-m-s (30 ft-lb-sec) ball bearing (HEAO) RWA plus a lab model magnetic bearing were tested. Additional tests were conducted on the 101H ball bearings used in these RWAs to determine bearing stiffness characteristics in the pre-breakaway, zero speed region. In general, it was concluded that high amplitude force and moment dynamic resonances existed in both the ball and magnetic bearing wheels that were tested. The amplitudes at these resonances are considerably higher than the unbalance forces and are in excess of ST requirements. The following recommendations were made relative to these test wheels:

- Enlarge the rotor diameter (and housing) to allow for greater rotor inertia and an efficient rotor design.

- Stiffen the rotor web to put the gyroscopic resonance at a high frequency.
- Replace the ac induction motor with a higher torque brushless dc motor.
- Add electronics integral with the wheel housing.

Using these recommendations as guidelines, SFS committed itself to an internally funded development program to provide a large RWA with prototype hardware to satisfy ST performance requirements. This RWA was fabricated from a previous Sperry program's residual hardware.

Then SFS, under contract to MSFC (Contract No. 8-31998), conducted a test program to measure and record the emitted vibration characteristics of the improved design ST RWA. The results of that program are reported herein.

1.3 OBJECTIVE

The principal technical objective of this test program was to characterize emitted vibration forces and moments over required ST speed, temperature and launch environments.

1.4 APPROACH

The overall technical approach to this program was to apply special rotor balance technique to the ST RWA at nominal operating conditions (1500 rpm, room temperature and pressure) achieving the lowest possible static and dynamic levels, then place it on the Emitted Vibration Measurement Fixture (EVMF) so that emitted forces and moments along and about three mutually perpendicular axes could be measured and recorded. Measurements were made over the nominal operating range of ±1500 rpm. After this data base was established, emitted vibration sensitivities to both temperature and vibration were measured.

SECTION 2.0

SUMMARY AND CONCLUSIONS

SECTION 2.0

SUMMARY AND CONCLUSIONS

This test program has measured the emitted forces and moments characteristics of the ST RWA under room temperature and pressure, thermal extremes, and vibratory conditions. The RWA/EVMF was calibrated statically and dynamically then background noise was measured with the ST RWA not operating. A baseline set of forces and moments of the ST RWA along and about three mutually perpendicular axes were recorded at room ambient. The unit was exposed to 110°F and 30°F ambient temperatures, respectively, with the emitted vibration characteristics measured at these temperatures. The RWA was also exposed to both +140°F and -30°F storage temperatures with measurements made before and after exposure. Finally, the unit was submitted to random vibration at an overall level of 6.5 grms, for 1.5 minutes along the three perpendicular axes. Emitted vibration was measured before and after this exposure. In addition, a low level resonance search was made of the unit to establish major structural resonances.

The overall emitted vibration characteristics of the SFS ST RWA are in agreement with the key goals established for this program, which were based on known ST requirements at the beginning of the effort. Table 2-1 gives the characteristics of the ST RWA measured during the program plus the key goals mentioned above. It also contains predicted characteristics based on design, or from previous program test data. The temperature and vibration sensitivities shown are those which were concluded to be a function of rotor unbalance changes and not associated with either spin motor nor rotor electronics changes.

TABLE 2-1

MEASURED ST RWA CHARACTERISTICS

Parameter	Value		Units	
Rotor Inertia	.39	.29	$N-m-s^2$	$ft-lb-sec^2$
Total Weight (including electronics)	23.5(24.3)[2]	51.8 (53.5)	Kg	lb
Rotor Weight	10.4	23	Kg	lb
Rotor Outer Diameter	.5	19.5	m	inches
Max Force (ambient)	.013 (.018)	.003 (.004)	N	lbf
Max Moment (ambient)	.0007 (.0045)	.006 (.040)	N-m	in.-lbf
Avg Drag Torque at 1500 rpm and 70°F	.009 (.01)	1.4 (1.5)	N-m	oz-in.
Major Resonant Frequencies				
Rotor Along Spin Axis	75 (> 65)	75 (> 65)	Hz	Hz
Rotor About Cross Axis	260 (> 250)	260 (> 250)	Hz	Hz
[1]Max Temperature Sensitivity				
Force	3.5×10^{-5}	8×10^{-6}	N/°F	lbf/°F
Moment	5.8×10^{-4}	5×10^{-4}	N-M/°F	in.-lbF/°F
[1]Max Change to Random Vibration				
(6.5 grms overall)				
Force	Factor of 4 increase	Factor of 4 increase	—	—
Moment	Factor of 1.3 increase	Factor of 1.3 increase	—	—
Predicted ST RWA Characteristics				
Angular Momentum at 1500 rpm	62.3	46	N-m-s	ft-lb-sec
Output Torque Over Speed Range	±.5	±71	N-m	oz-in.
Run Power, max at 1500 rpm and 70°	12	12	watts	watts
Power at Maximum Speed and and Torque	160	160	watts	watts
Torque Linearity over Speed Range	3	3	percent	percent
Torque Resolution	.05	.05	percent	percent
<u>General</u>				
Spin Motor Type	DC Brushless			
Bearing Type	101H Angular Contact (DF)			
Speed Pickoff	Magnetic			
Design Life	7	7	years	years

1. Rotor Unbalance Related
2. Numbers in parentheses are key goals

The following conclusions have been drawn from this contract effort:

1) The SFS three-axis, hard-mount, Emitted Vibration Measurement Fixture provides an efficient means for measuring small reaction wheel force and moment signatures. Emitted vibrations can be accurately measured over a range of 10 to 200 Hz with force and moment resolutions of .002N (.0005 lbf) and .00006N-m (.0005 in.-lbf), respectively.

2) Baseline data shows that the ST RWA can be initially balanced to emitted vibration levels less than .018N (.004 lbf) and .0045N-m (.040 in.-lbf) along and about the three primary axes.

3) Predominant ST RWA emitted vibration frequencies are at wheel speed, 2X wheel speed and 3.9X wheel speed. Forces and moments at spin bearing retainer frequency were not detectable above the noise level. The 2X wheel speed peaks were concluded to be due to demodulation voltage offset in the BDC motor electronics. The 3.9X wheel speed peaks appear only above 500 rpm and were concluded to be due to a very low level source being amplified by the RWA/fixture structural resonance.

4) ST RWA emitted vibration temperature sensitivity over the operating temperature range of 110° to 30°F is very small and almost non-existent (see Table 2.-1).

5) Factors must be applied to baseline emitted vibration levels to allow for changes that will occur when the ST RWA is exposed to three axes of random vibration (see Table 2-1).

SECTION 3.0

RECOMMENDATIONS FOR FURTHER STUDY

SECTION 3.0

RECOMMENDATIONS FOR FURTHER STUDY

3.1 INTRODUCTION

Several areas for further study were discovered during the test program. This section generally discusses approaches to each of these potential study areas. The studies could either be done as separate technology studies or as part of the ST RWA procurement development phase.

3.2 RECOMMENDATIONS

1. A significant forcing function was discovered at two times wheel speed, primarily as a moment about the spin axis. It was concluded that this particular peak is a function of the BDC spin motor and/or electronic anomalies rather than rotor unbalance. This task would involve a comprehensive dimensional check of the RWA housing and spin motor to detect any stator or housing ellipticity and rotor eccentricity. Once deficiencies were identified, corrective machining would be performed to reduce these effects to a minimum. Also involved would be tests to determine the amount of demodulation voltage offset in the rotor electronics and make changes to reduce this offset to a minimum. As part of this task, intentional and known anomalies would be introduced in both the motor and electronics to determine the sensitivity of the emitted vibration levels.

2. It is anticipated that ST attitude control requirements will necessitate a near zero wheel speed sensor. Devices such as proximity probes can be substituted for the existing magnetic pickoffs to reduce the lowest detectable speed from approximately 25 rpm to 5 rpm. Another candidate speed sensor is a brushless dc tachometer. SFS has developed a low ripple sensor for a gimbal drive system that is capable of measuring rates in the tens of microradians-per-second range.

3. The scope of the reported program did not include tests to determine the overall RWA torque output characteristics. It is recommended that a comprehensive test program be conducted to measure such parameters as peak torque output torque ripple, torque resolution, torque linearity and peak torque power. This would be done under all environmental conditions. It is anticipated that the SFS Emitted Vibration Test Fixture could be used for these tests, however, a suitable torque transducer would also be investigated to determine the best system.

4. Develop a complete and detailed mathematical model of the ST RWA. Identify and quantify the source of each major peak in the frequency spectrums such that frequency and amplitude levels can be accurately predicted over the operational speed range. This effort would include detailed computer simulations as well as hardware tests to verify and supplement the simulations. This model could be used in the overall ST mathematical model of the prime contractor and function as a general model for any spacecraft using RWAs as control devices.

SECTION 4.0

SPACE TELESCOPE REACTION WHEEL DESCRIPTION

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SPACE TELESCOPE REACTION WHEEL DESCRIPTION

A complete description of the SFS ST Reaction Wheel is found in the program proposal, SFS Pub. No. 81-1288-01-00.

SECTION 5.0

TEST EQUIPMENT AND CALIBRATION PROCEDURES

SECTION 5.0

TEST EQUIPMENT AND CALIBRATION PROCEDURES

5.1 TEST SETUP DESCRIPTION

A complete description of the SFS emitted vibration measurement fixture is found in the Program Proposal, SFS Pub. No. 81-1288-01-00.

5.2 CHARACTERIZATION AND BACKGROUND NOISE TESTS

Upon completion of static calibration, the ST RWA unit and Emitted Vibration Fixture system are characterized with respect to resonant frequencies and transmissibilities. These tests are performed using Ling Model 203 vibrators to impose a known sinusoidal excitation on the nonoperating ST RWA.

The body of the vibrator is suspended on an isolation system with a natural frequency much lower than the frequencies of interest in the ST RWA/fixture system. The armature of the vibrator is rigidly attached to the ST RWA. As the vibrator is excited, the body moves with respect to the armature and imposes a force on the ST RWA. A force transducer mounted on the "stinger", which connects the shaker to the ST RWA, measures the force input and is used as the feedback control sensor in the force control loop. The vibrator is sinusoidally excited by a Spectral Dynamics SD104A Sweep Oscillator through a MacIntosh amplifier. A typical setup is illustrated in Figure 5-1. Frequencies between 10 and 500 Hz are covered at a sweep rate of .5 decade per minute. During the frequency sweeps, the output of the force transducer provides the feedback enabling the control electronics to vary the MacIntosh gain as needed to maintain the calibration force at a selected constant level. For moment axis calibration, two vibrators driven 180 degrees out of phase by the MacIntosh amplifier are used (Figure 5-2). In this mode, the resistive load of one of the shakers is adjusted until the outputs of the two shakers are equal. Calibration inputs of .25 lbf rms and 2 in.-lbf rms were utilized during these tests. Outputs of the EVMF were summed by the EVMF electronics to resolve the forces and moments into proper axes. The response output of the fixture force transducers is analyzed by a Spectral Dynamics SD101B spectrum analyzer with a 5-Hz bandwidth. Tuning for

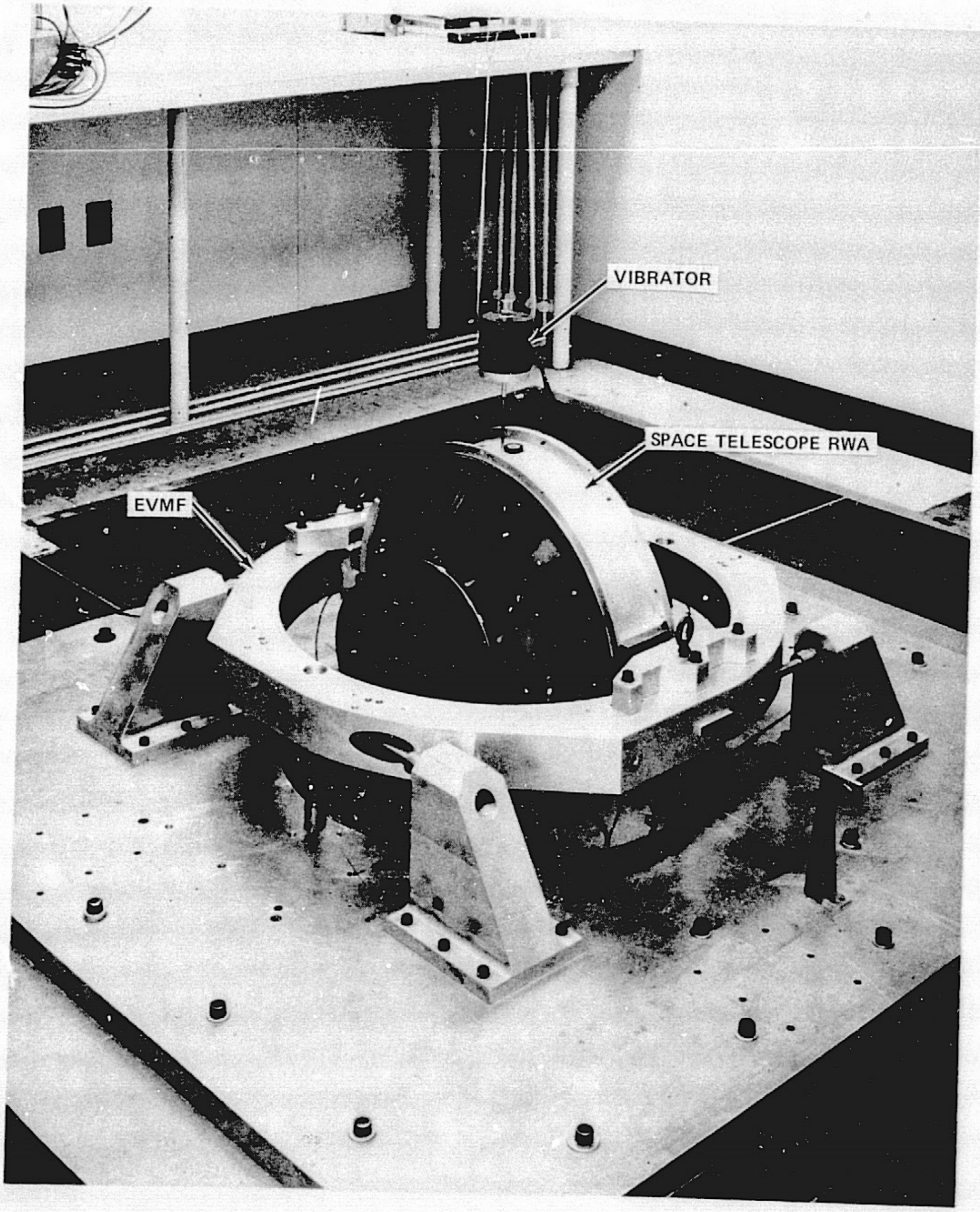

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Figure 5-1
Typical Characterization Test Set-Up for Force Axis Calibration

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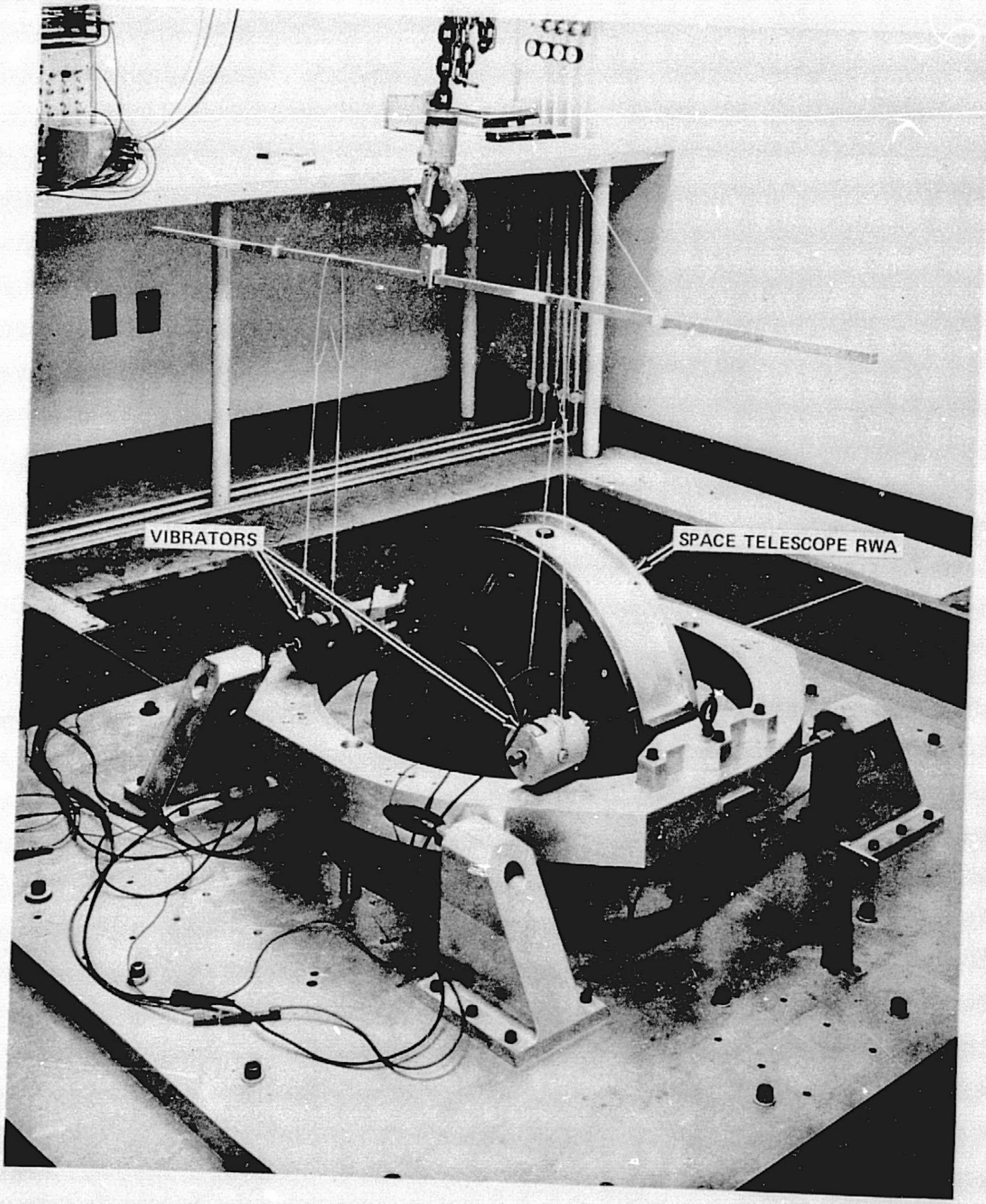

Figure 5-2
Typical Characterization Test Set-Up for Force Axis Calibration

the spectrum analyzer is provided by the same sweep oscillator driving the vibrator so that the two are synchronized. This filtered response is recorded on an X-Y plotter. The orientation of the vibrator and its attach point to the ST RWA are varied in order to successively excite each of the fixture axes. A schematic diagram, Figure 5-3, illustrates the instrumentation described in these characterization tests.

The data obtained on the X-Y plotter, illustrated in Figures 5-4 through 5-9, represent the response of each axis to calibration vibrator inputs. The ordinate of these graphs presents the ratio of the magnitude of the transmitted calibration excitation response to the input calibration forcing function, expressed in decibels. The abscissa is the excitation frequency. If there were no structural frequencies within the frequency range investigated, each plot would simply be a horizontal line at 0 dB.

Figures 5-4 through 5-6 illustrate traces of the force output along the three mutually perpendicular axes. The excitation force is .25 pound. Figures 5-7 through 5-9 show the moment output traces about the three principal axes when the system is excited by an input moment of 2 pound-inches at frequencies varying from 10 to 500 Hz. The data indicates basically smooth frequency response to the structural system up to system response.

After the fixture is statically calibrated and characterized for resonance transmissibility with the test unit in place, the background noise is determined. This procedure is required to ensure that the emitted vibration from an operating unit can be differentiated from any extraneous outputs from outside the EVMF. Because the sensitivities of the test setup were so high every precaution is required to assure the absence of outside influence to the test unit.

The test equipment used to determine the background noise consists of a Spectral Dynamics SD330 Real Time Analyzer (RTA) driving an X-Y plotter. The calibrated signal from the EVMF electronics is inputted directly into the RTA. The analysis range is typically 0 to 100 Hz and dictated an analysis bandwidth of .6 Hz (2.5 second memory period).

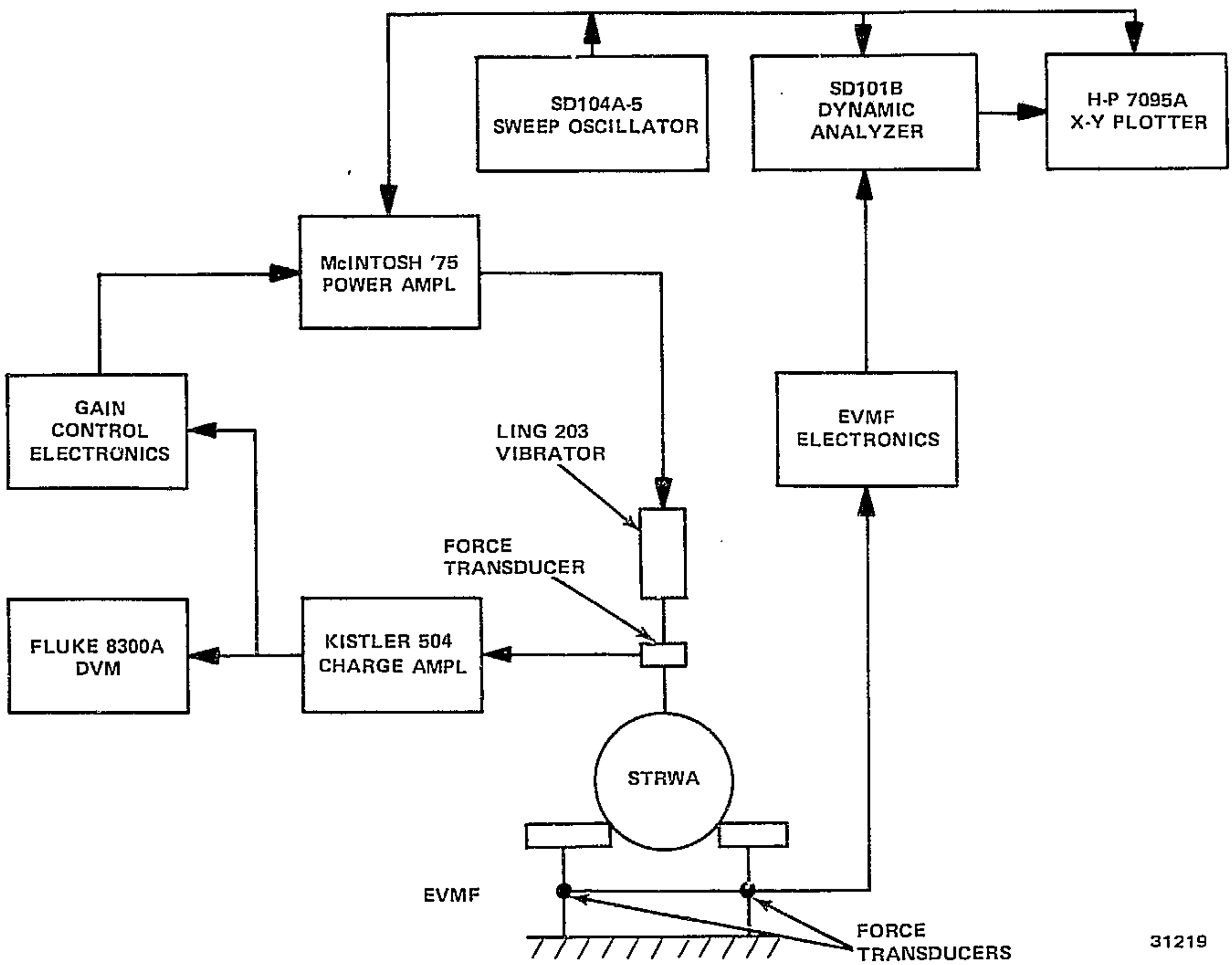

Figure 5-3
Instrumentation Block Diagram

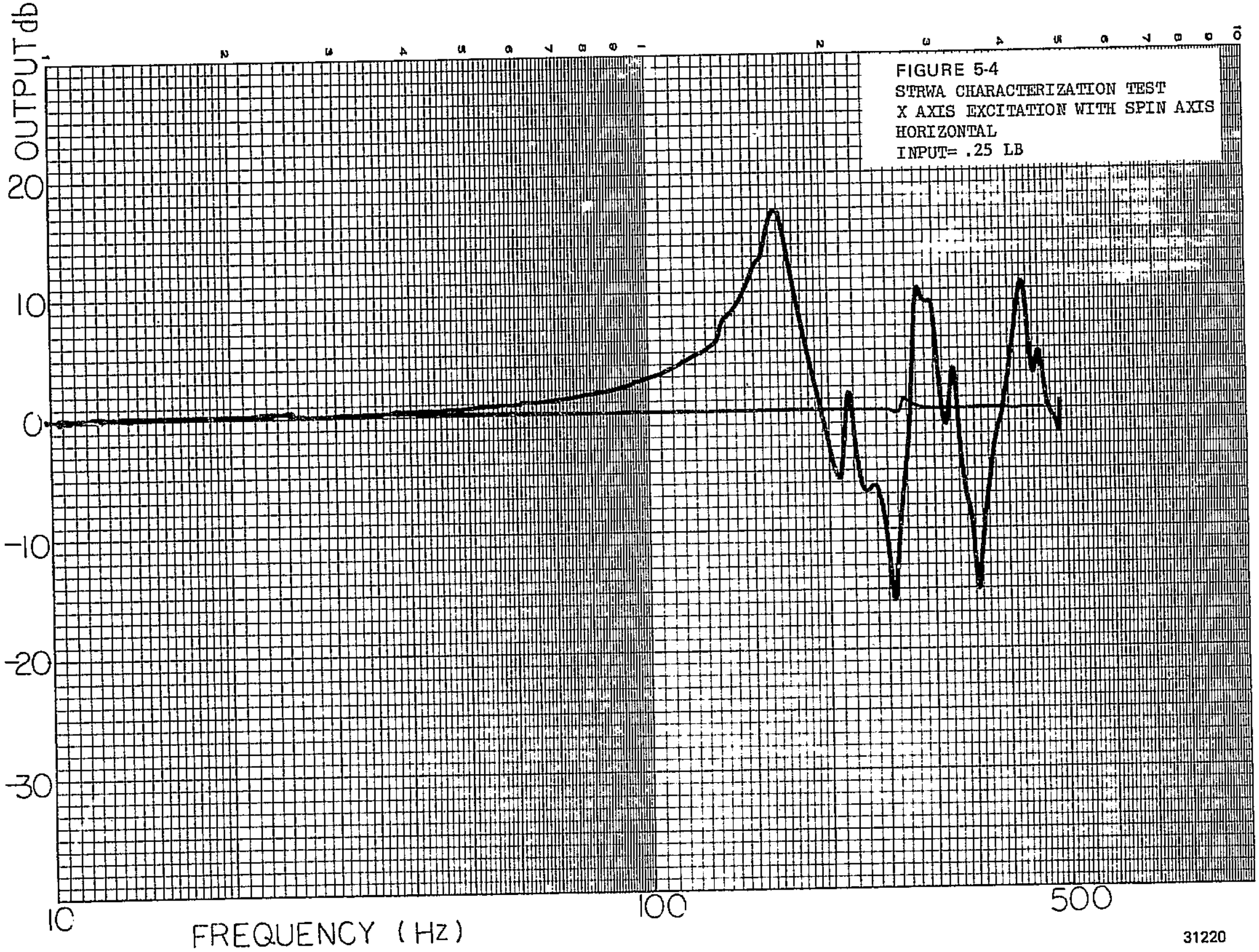
FIGURE 5-4
STRWA CHARACTERIZATION TEST
X AXIS EXCITATION WITH SPIN AXIS
HORIZONTAL
INPUT= .25 LB
OUTPUT db
20
10
0
-10
-20
-30
10
100
500
FREQUENCY (Hz)

31220

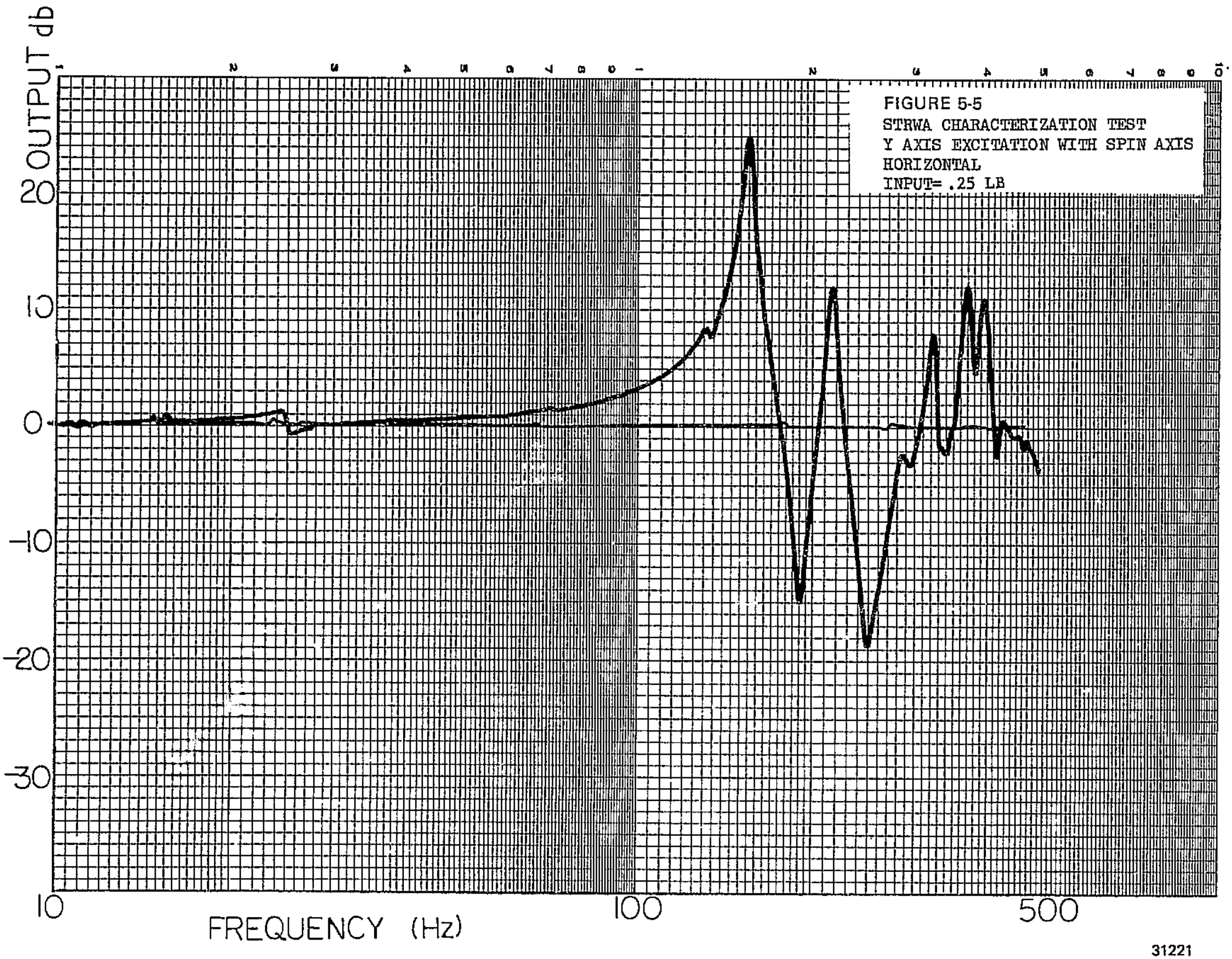

FIGURE 5-5
STRWA CHARACTERIZATION TEST
Y AXIS EXCITATION WITH SPIN AXIS HORIZONTAL
INPUT= .25 LB

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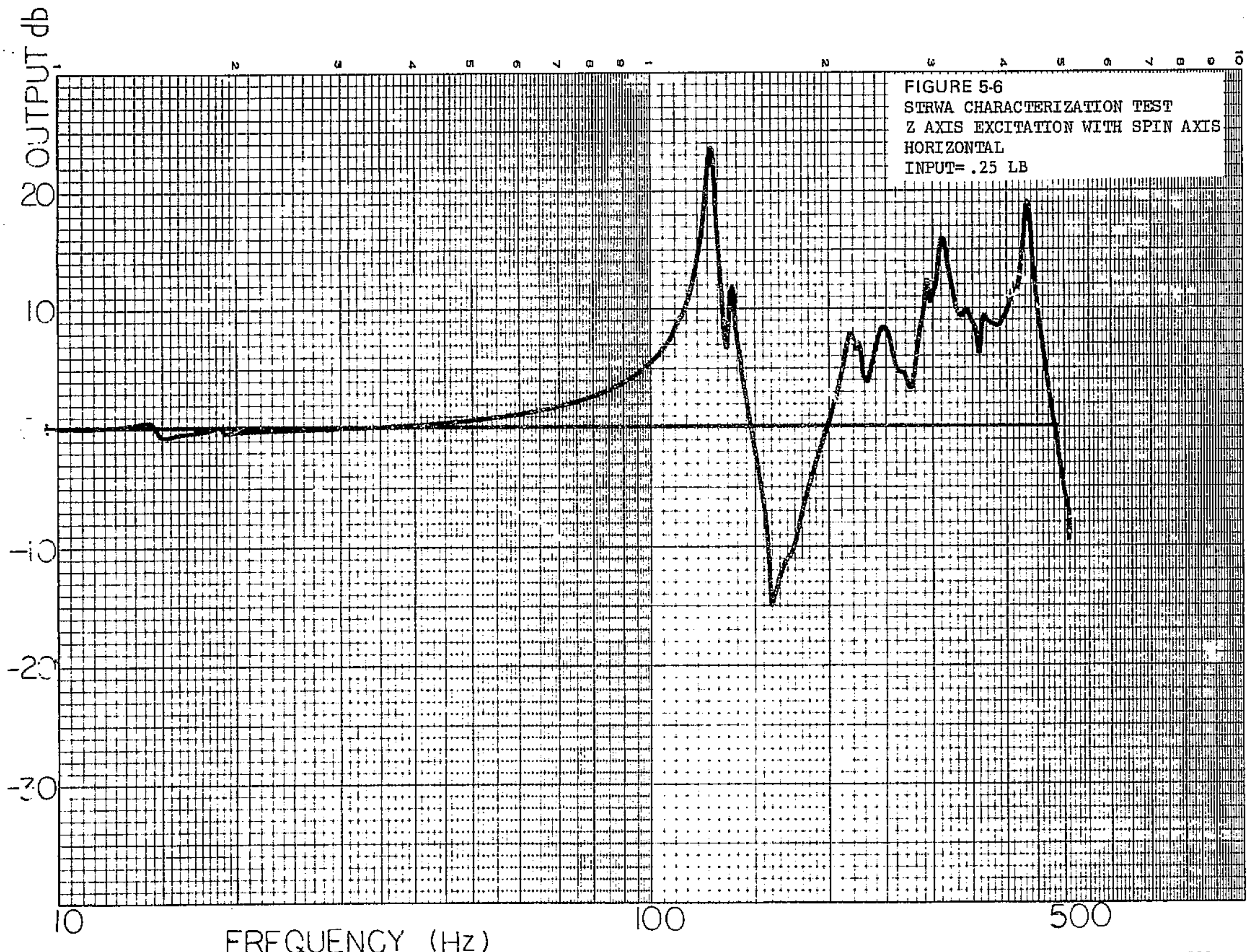
FIGURE 5-6
STRWA CHARACTERIZATION TEST
Z AXIS EXCITATION WITH SPIN AXIS
HORIZONTAL
INPUT= .25 LB
OUTPUT db
20
10
-10
-20
-30
10
100
500
FREQUENCY (Hz)

31222

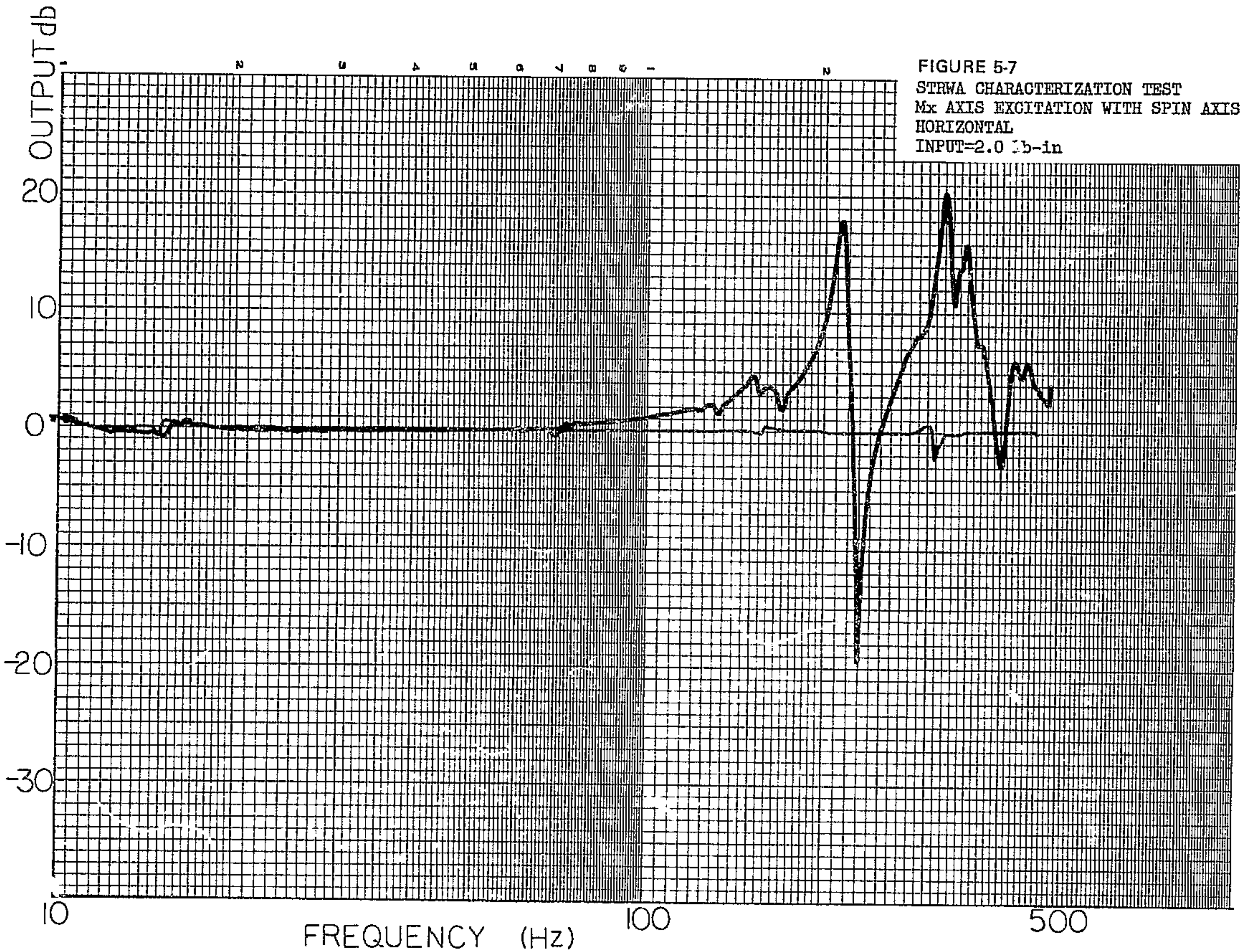

FIGURE 5-7
STRWA CHARACTERIZATION TEST
Mx AXIS EXCITATION WITH SPIN AXIS
HORIZONTAL
INPUT=2.0 lb-in

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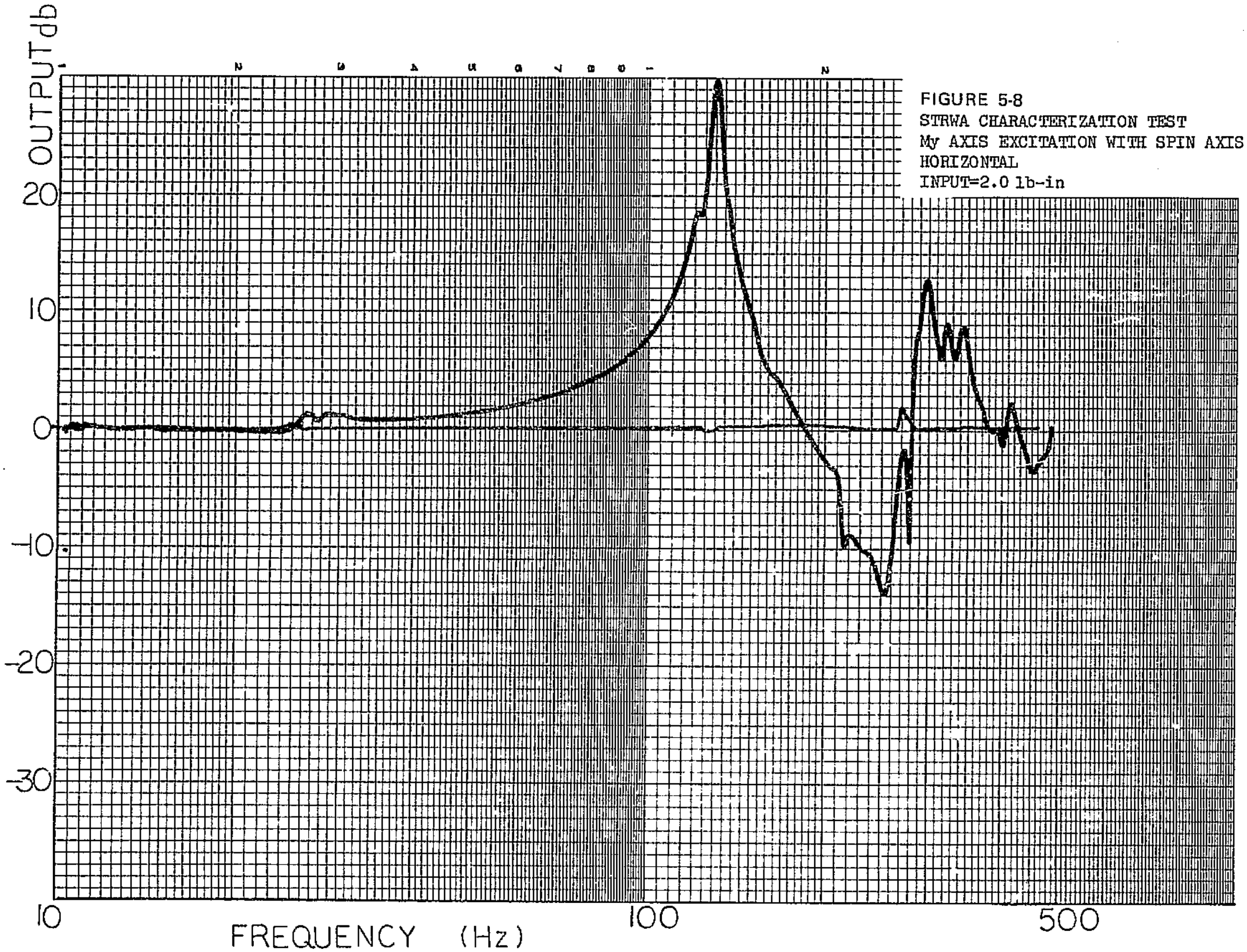


FIGURE 5-8
STRWA CHARACTERIZATION TEST
My AXIS EXCITATION WITH SPIN AXIS HORIZONTAL
INPUT=2.0 lb-in

31224

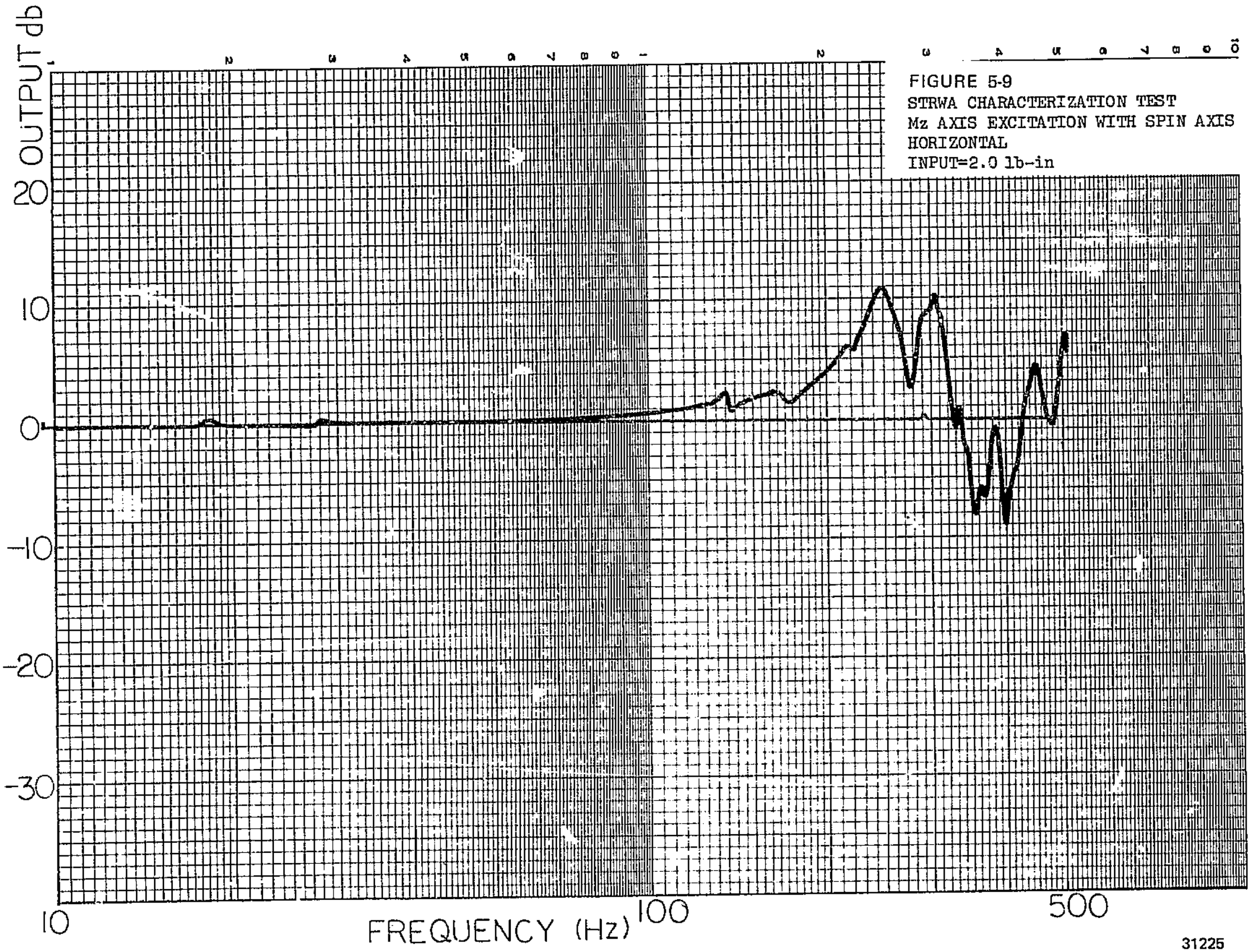


FIGURE 5-9
STRWA CHARACTERIZATION TEST
Mz AXIS EXCITATION WITH SPIN AXIS
HORIZONTAL
INPUT=2.0 lb-in

31225

Typical background traces are shown in Figures 5-10 and 5-11. All six axes are recorded on one sheet using the same output scaling used when taking data during unit operation tests. The ordinate scaling, however, is approximate as each axis has its own calibration constant as determined during the static calibration tests. To obtain the correct magnitude desired, multiply the peak reading in inches by the appropriate axis scale factor in Table 5-1.

TABLE 5-1

ST RWA SCALING FACTORS FOR APPROXIMATE SCALES ON EVMF DATA CHARTS

Axis		Multiply Readings in Inches by
F_x	N (lb)	.77 (.89)
F_y	N (lb)	.80 (.92)
F_z	N (lb)	.89 (1.00)
M_x	N-m (lb-in.)	1.11 (1.00)
M_y	N-m (lb-in.)	.88 (.78)
M_z	N-m (lb-in.)	1.03 (.91)

The major anomaly in the background noise traces occurred at 60 Hz, which represents ac power disturbance. This spike was normally higher on the moment axes because these signals were more sensitive and extensively processed in the EVMF electronics. Some effort was expended to eliminate or reduce the size of this 60 Hz disturbance with little success. It was determined that a significant redesign of the EVMF electronics was required to completely eliminate this disturbance.

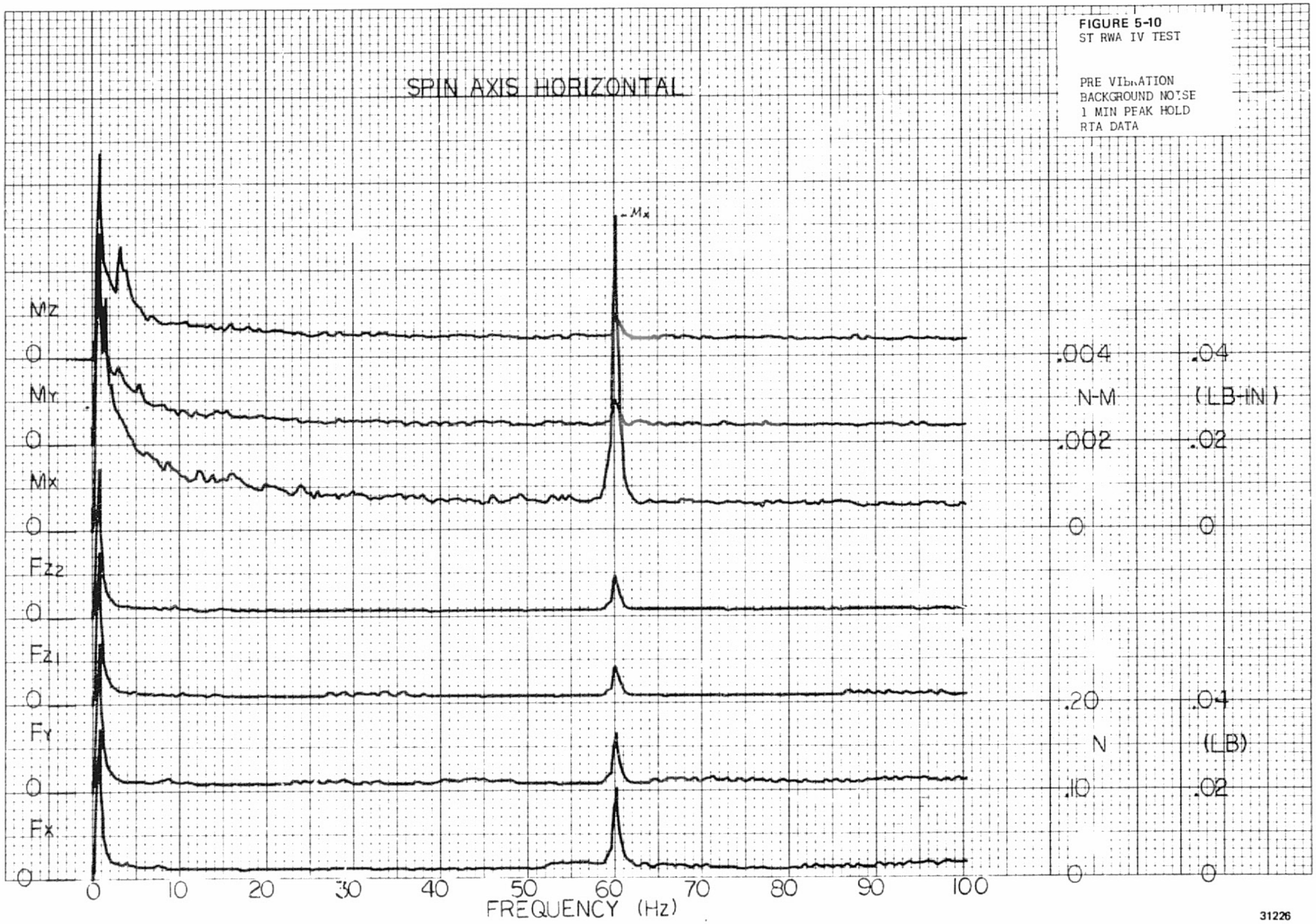


FIGURE 5-10
ST RWA IV TEST
PRE VIBRATION
BACKGROUND NOISE
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mx
MZ
MY
MX
FZ2
FZ1
FY
FX
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.004
N-M
.002
.04
(LB-IN)
.02
.20
N
.10
.04
(LB)
.02
31226

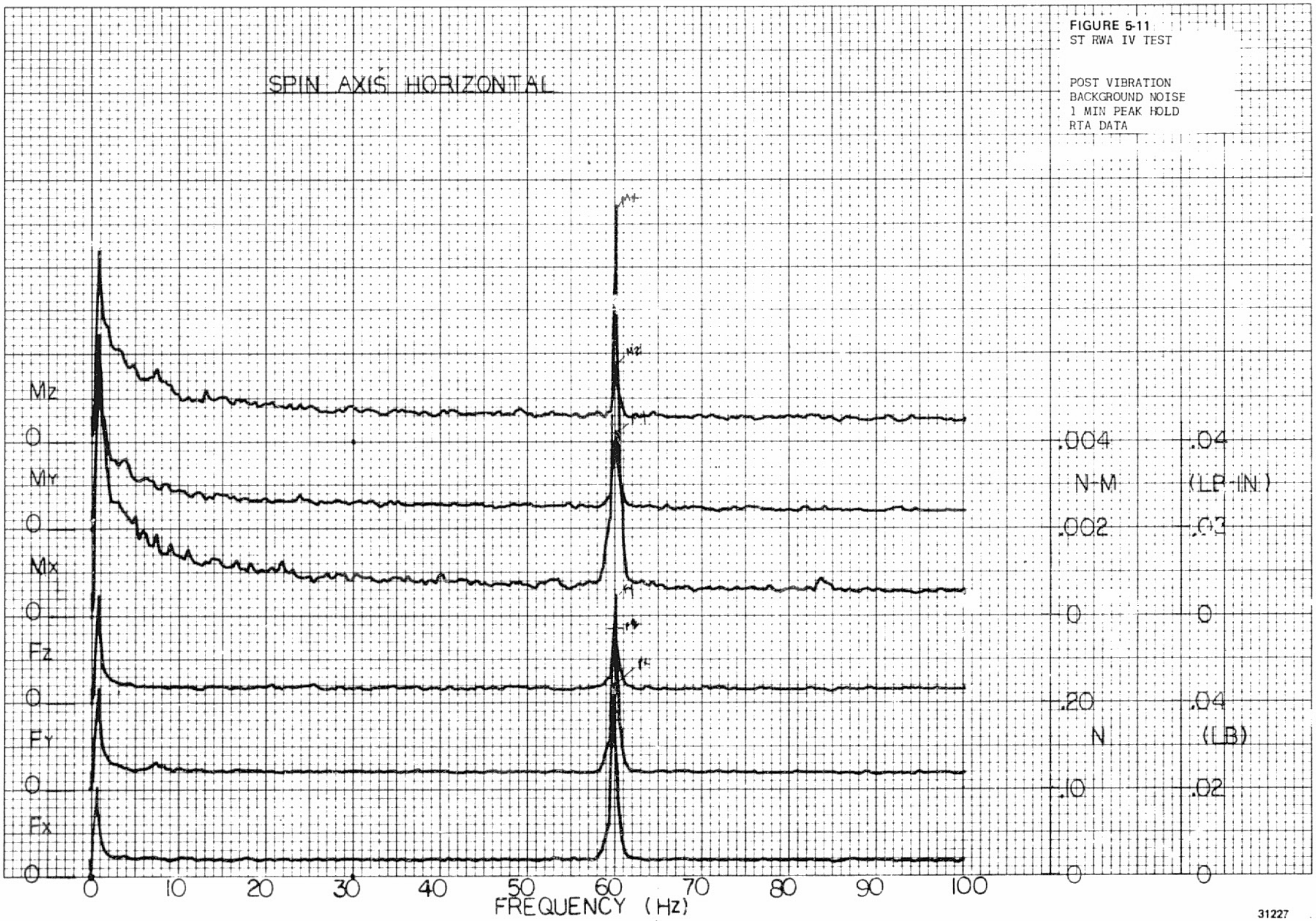


FIGURE 5-11
ST RWA IV TEST
POST VIBRATION
BACKGROUND NOISE
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
Mx
Fz
Fy
Fx
.004
.04
N-M
(LB-IN)
.002
.02
0
.20
N
(LB)
.10
FREQUENCY (Hz)
0
10
20
30
40
50
60
70
80
90
100
31227

The low frequency disturbance below 1 Hz was associated with the Real Time Analyzer (RTA) and is characteristic of that test equipment. This peak appeared on the internal calibration trace of the RTA and could not be eliminated from the RTA output. The large displacement at low frequencies on the moment axes was associated with the EVMF electronics and appeared on all test data.

All traces were taken with the RTA in the peak hold averaging mode and observed for a 1-minute period. In this mode the peak signal attained during the 2.5-second memory period was retained in the RTA memory. The memory and display were updated every 2.5 seconds and displayed the largest value signal yet attained. After 1 minute the trace was locked in and recorded on the X-Y plotter producing the traces of Figures 5-10 and 5-11. The data for the operating tests was produced in the same manner.

SECTION 6.0

BASELINE TESTS

SECTION 6.0

BASELINE TESTS

The majority of testing done on the ST RWA during this phase was performed on the EVMF described in Section 5.0. This testing was aimed at characterizing the frequency and amplitude of any force and moment disturbances when operating the ST RWA from 0 to 1500 rpm in either rotation direction. This speed range was selected as being within the anticipated ST nominal operating requirements. The test spectrum investigated was predominately from 0 to 100 Hz with greatest emphasis on disturbances at wheel speed. All testing was recorded at steady state speeds using the 1 minute peak hold averaging mode of the RTA. This RTA mode precluded the recording of data while varying the speed of the ST RWA. However, the observation of EVMF data on the RTA while changing the ST RWA speeds from one steady state to another showed the trend of data as wheel speed was changed. The RTA peak hold mode provided confidence of observing the maximum amplitude disturbances produced by the ST RWA and sensed by the EVMF.

Prior to operating the ST RWA on the EVMF, the rotor was balanced on the Shenk balancing equipment. Rotor balancing was performed in the operational ST RWA housing using the operational bearings only after initial rough balancing was complete.

Two test conditions were resolved early in the test program to aid in evaluating subsequent test results. Because of the extensive environmental testing performed and the time allotted, the EVMF tests before and after each environmental exposure were all performed with the ST RWA spin axis horizontal and aligned along the Z axis. This orientation more closely simulates orbital conditions than spin axis vertical. Figure 6-1 illustrates this preferred orientation, the principal axes orientation is illustrated in Figure 5-1. Figures 6-2 and 6-3 are plots of the moment output about the trunnion mounting axis for both horizontal and vertical spin axis configurations and are typical of the data obtained in these tests. Examination of these traces showed almost identical magnitude and position of

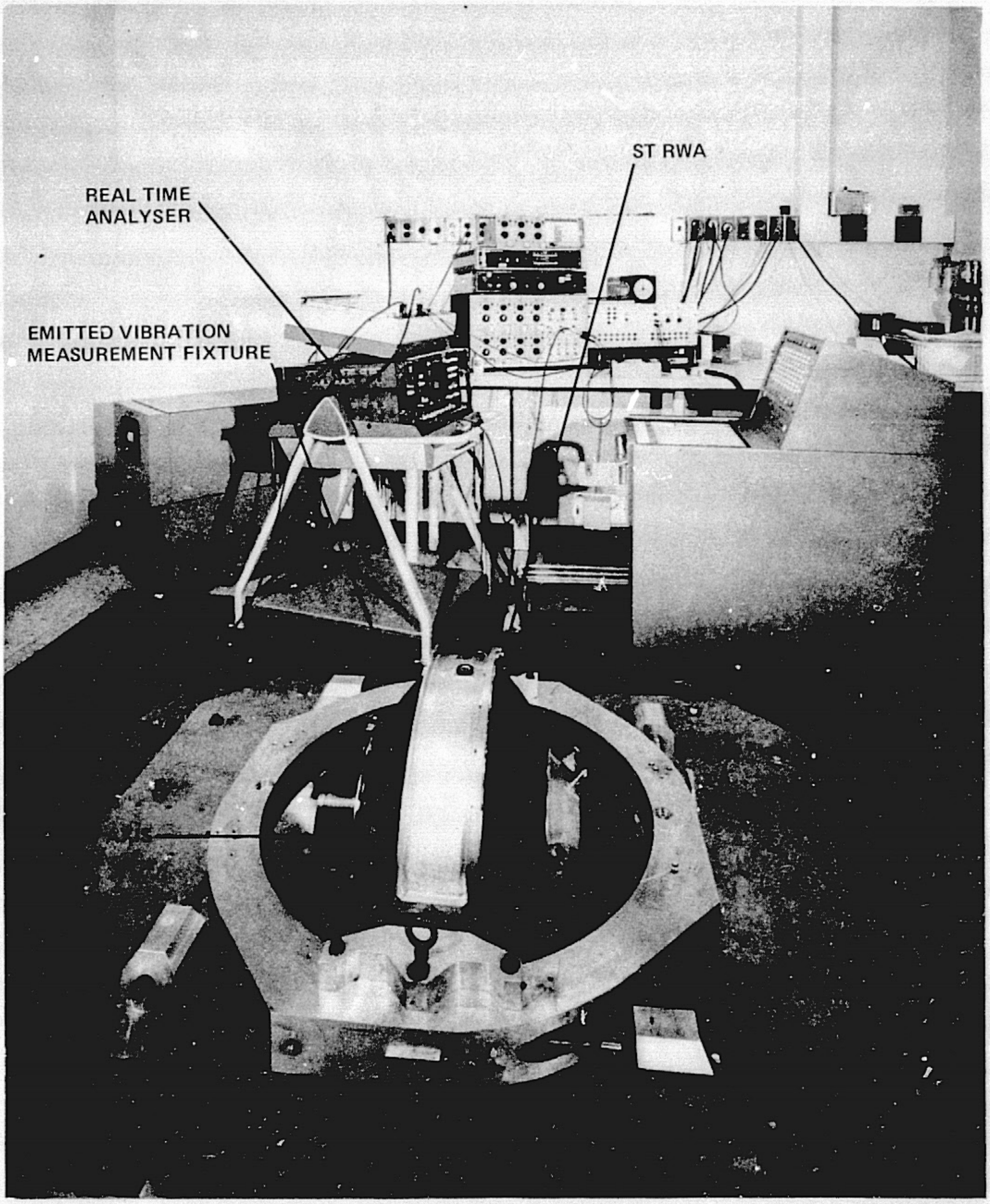


Figure 6-1
ST RWA Mounted on EVMF
in Preferred Orientation


FIGURE 6-2
ST RWA IV TEST
STEADY STATE SPEEDS
My AXIS
1 MIN PEAK HOLD
RTA DATA
CW DIRECTION
SPIN AXIS VERTICAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.004
.04
N-M
(LB-IN)
.002
.02
0
0
31314

FIGURE 6-3

ST RWA IV TEST
STEADY STATE SPEEDS
My AXIS

1 MIN PEAK HOLD
RTA DATA

31315

disturbance frequencies for both spin axis orientations. Because of this similar test data the remainder of the testing was performed in the spin axis horizontal configuration.

The second test condition, which duplicated test results, was the rotor rotation direction. Figures 6-4 and 6-5 illustrate the test data obtained for force along the spin axis for both clockwise and counterclockwise rotor rotation. The test results were again almost identical and warranted future testing to be performed in one direction only. Thus, subsequent testing was performed with the rotor rotating counterclockwise as viewed from the motor end.

The initial traces taken to establish a baseline emitted vibration performance level for the ST RWA are presented in Figures 6-3, and 6-6 through 6-10. The traces were taken at steady state rotor speeds in 200 rpm steps from 1500 rpm to 100 rpm over an analysis range of 0 to 100 Hz. Each figure illustrates a single axis of the six principle axes, F_x, F_y, F_z, M_x, M_y, M_z, analyzed on the EVMF. The data presented in this manner clearly differentiates the wheel speed related vibration phenomena from fixture related or non-wheel speed excited disturbances (note the 60 Hz electrical noise).

The M_z data shown in Figure 6-10 exhibited the highest disturbance in the 0 to 50 Hz frequency range. This peak occurred at 40 Hz with the wheel speed operating at 100 rpm with a magnitude of .0064 N-M (.0569 lb-in.). Figure 6-10 represents moment disturbances about the spin axis attributed to cogging torques. This peak is thus a cogging disturbance at 24 times wheel speed which remains constant throughout the wheel speed range. This corresponds to the 24 teeth in the brushless dc motor stator. Another moment disturbance about the spin axis (Figure 6-10) occurred at twice wheel speed and was apparent at all wheel speeds tested. The magnitude was .002 N-M (.018 lb-in.) and remained constant at all wheel speeds. This 2X wheel speed disturbance was produced by either one or a combination of:

- Motor stator elliptic and rotor eccentric to axis-of-rotation
- Demodulation offset in the BDC motor electronics

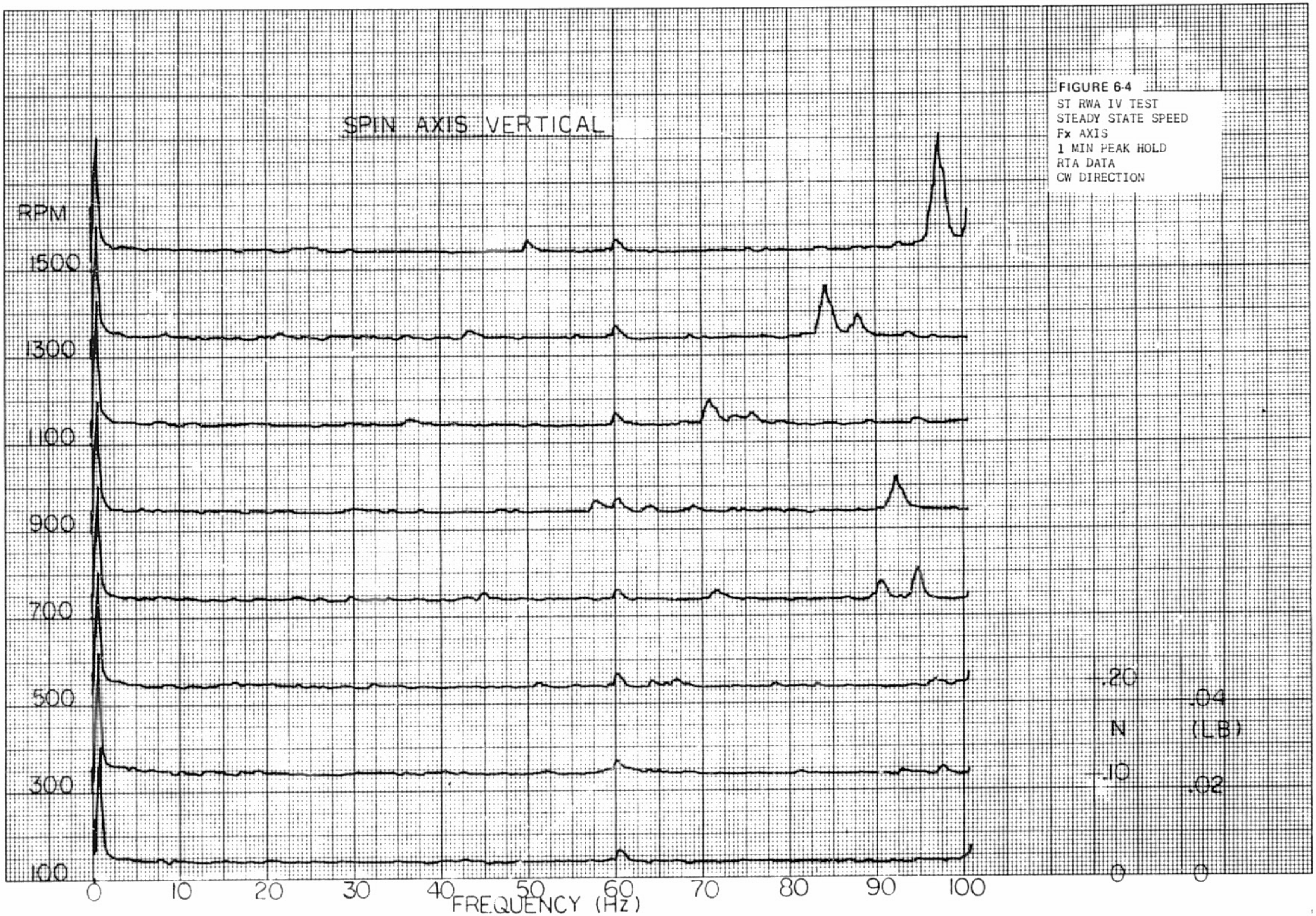
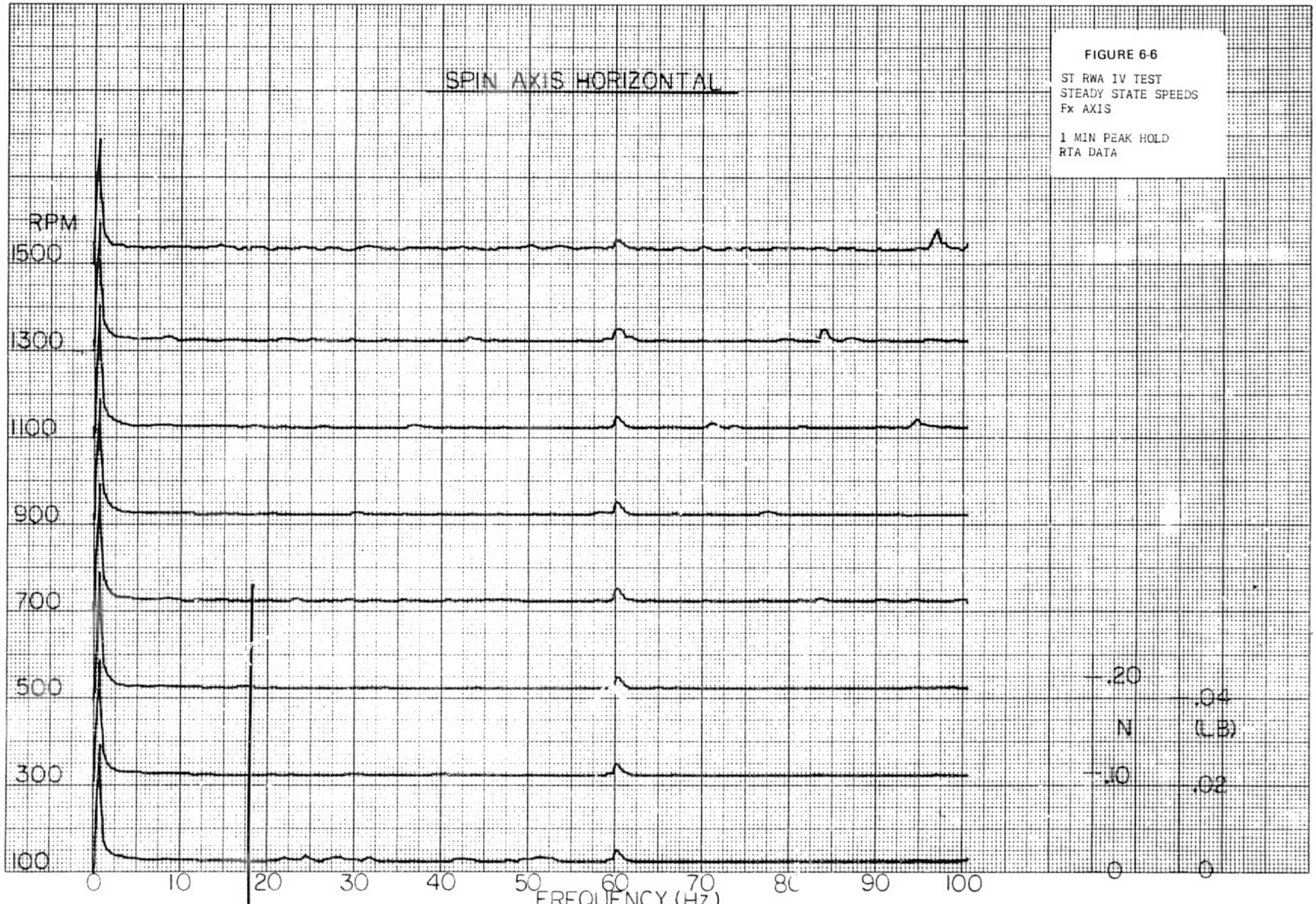


FIGURE 6-4
ST RWA IV TEST
STEADY STATE SPEED
Fx AXIS
1 MIN PEAK HOLD
RTA DATA
CW DIRECTION

31316

FIGURE 6-5
ST RWA IV TEST
STEADY STATE SPEED
Fx AXIS
1 MIN PEAK HOLD
RTA DATA
CCW DIRECTION

31317



SPIN AXIS HORIZONTAL
FIGURE 6-6
ST RWA IV TEST
STEADY STATE SPEEDS
Fx AXIS
1 MIN PEAK HOLD
RTA DATA
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
N
.10
0
.04
(LB)
.02
0

31318

FIGURE 6-7

ST RWA IV TEST
STEADY STATE SPEEDS
Fy AXIS
BASELINE
1 MIN PEAK HOLD
RTA DATA

31256

FIGURE 6-8

ST RWA IV TEST
STEADY STATE SPEEDS
Fz AXIS
BASELINE
1 MIN PEAK HOLD
RTA DATA

31257


FIGURE 6-9
ST RWA IV TEST
STEADY STATE SPEEDS
Mx AXIS
BASELINE
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.012
.12
N-M
(LB-IN)
.006
.06
0
0
31258

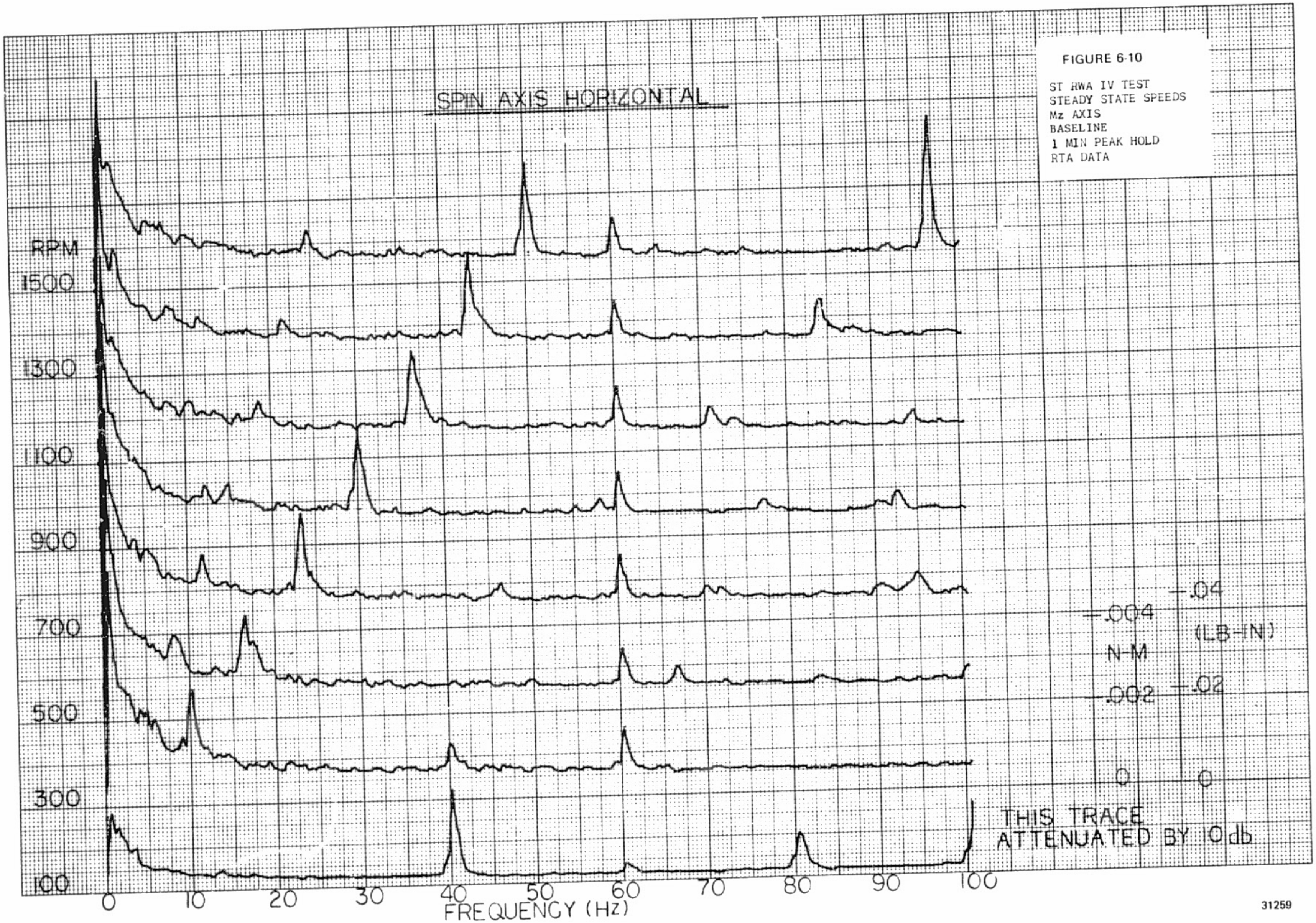


FIGURE 6-10
ST RWA IV TEST
STEADY STATE SPEEDS
Mz AXIS
BASELINE
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.004
.04
(LB-IN)
N-M
.002
.02
0
0
THIS TRACE
ATTENUATED BY 10db
31259

The geometric anomaly would cause radial forces to be generated by the spin motor, whereas the electronic offset would cause an increase in cogging torque about the spin axis. Since the M_z or spin axis moment data showed the highest peaks for the 2X wheel speed disturbance, the primary anomaly would be motor cogging torque about the spin axis.

The peak at approximately 3.9X wheel speed evident in Figures 6-3, 6-8 and 6-10, or the M_y, F_z and M_z axes, does not correspond to an even multiple of wheel speed. Nor does it correspond to a spin bearing anomaly multiple of wheel speed. This disturbance is not evident below 500 rpm, however, it rises, exponentially at speeds higher than 500 rpm. This exponential rise corresponds to the rise in the RWA/EVMF structural resonance. It therefore appears that this disturbance is low level and is merely exciting the measurement system structure. It poses no problem to a spacecraft system unless there is a critical resonance at frequencies greater than 60 Hz and is sensitive to the indicated levels.

Table 6-1 presents the levels of emitted vibration at 1500 rpm from the baseline data in Figures 6-3, and 6-6 through 6-10. These values represent peak levels up to 1500 rpm since the emitted vibration levels at wheel speed tend to follow the speed squared law. The values in Table 6-1 can be compared to the goals for initial maximum ambient levels of .018N (.004 lbf) and .0045 N-M (.040 in.-lbf).

TABLE 6-1

BASELINE AMBIENT EMITTED VIBRATION IN 25 HZ

F_x	F_y	F_z	M_x	M_y	M_z
Newton (Pounds)			Newton-Meter (Pound-Inch)		
.0044 (.0010)	.0067 (.0015)	.0133 (.0030)	.0005 (.0042)	.0007 (.0062)	.0005 (.0047)

SECTION 7.0

TEMPERATURE TESTS

SECTION 7.0

TEMPERATURE TESTS

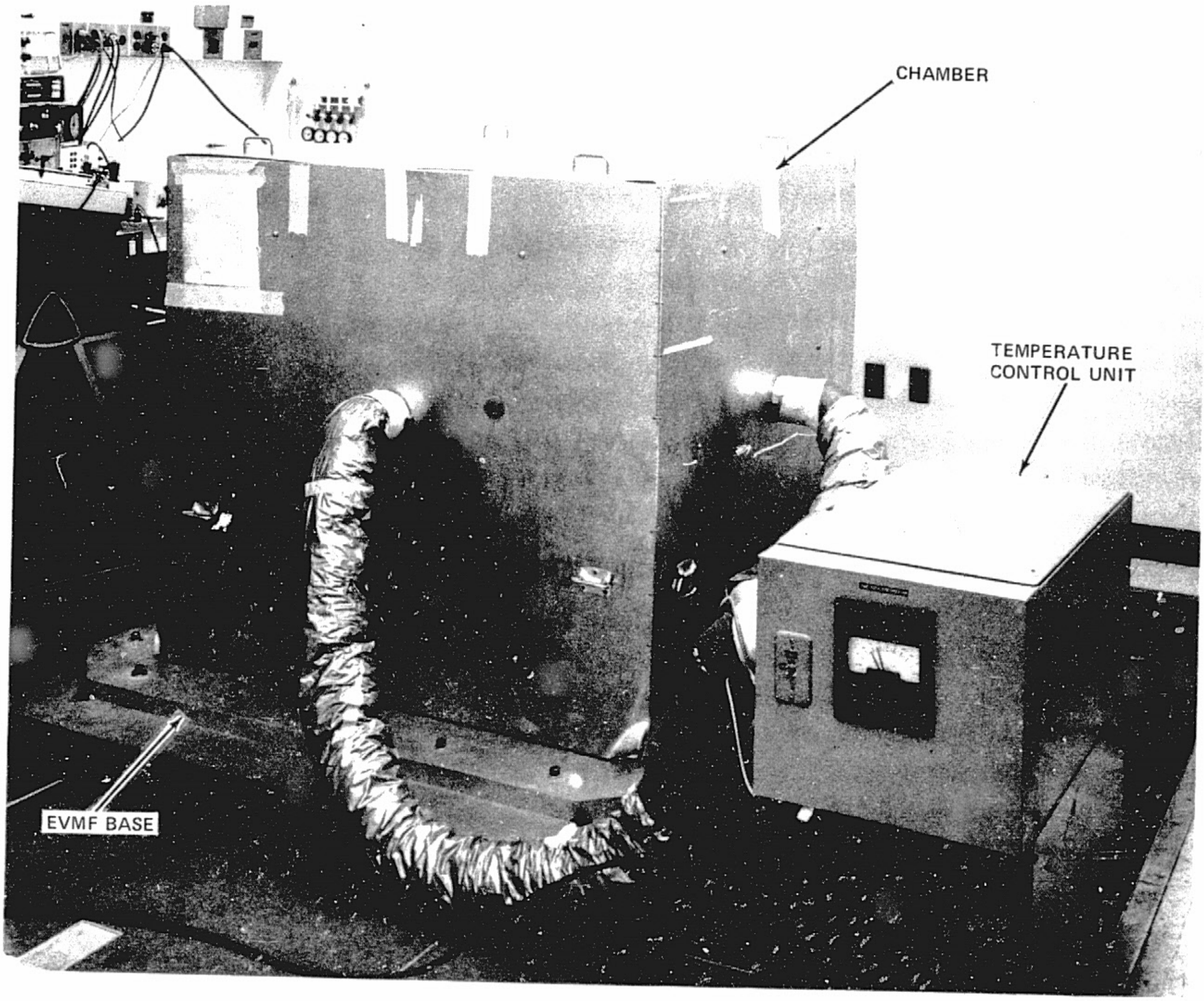
The ST RWA was subjected to four temperature tests: two operating and two for storage capabilities (i.e., non-operating). The operating high and low temperature limits were 44°C (110°F) and 0°C (30°F) and the limits for the non-operating tests were 60°C (140°F) and -35°C (-30°F). The operating tests were performed on the EVMF with complete force and moment data taken at the temperature extremes. The EVMF data was taken before and after each storage temperature exposure to determine the consequences of subjecting the unit to these environments.

The equipment required to perform operating EVMF tests at high and low temperature is illustrated in Figure 7-1. The chamber had 10 cm (4 in.) thick walls of insulating foam on five sides supported by an aluminum sheet structure and was placed directly over the EVMF ring containing the ST RWA. Additional insulating foam was placed under the ST RWA to help prevent the EVMF aluminum base from being a significant thermal sink. Four monitor thermocouples were placed inside the chamber to record temperatures at the following locations:

- the top of the ST RWA
- the bottom of the ST RWA
- the EVMF support ring
- the enclosure interior air temperature

EVMF data was taken when the top and bottom thermocouples mounted on the ST RWA indicated stable identical readings of the target temperature. The temperature control unit contained a heating-cooling coil and an air distribution system to circulate the temperature regulated air. The cooling capability could be enhanced by introducing dry ice around the cooling coil or injecting CO_2 gas into the air circulating system to extend the low temperature capability to approximately -13°C (0°F).

The EVMF calibration could not be performed at the temperature extremes with the thermal chamber in place over the EVMF. It was expected that the static calibration levels would vary due to thermal stresses imposed on the



31296

Figure 7-1
Thermal Chamber for EVMF Temperature Tests

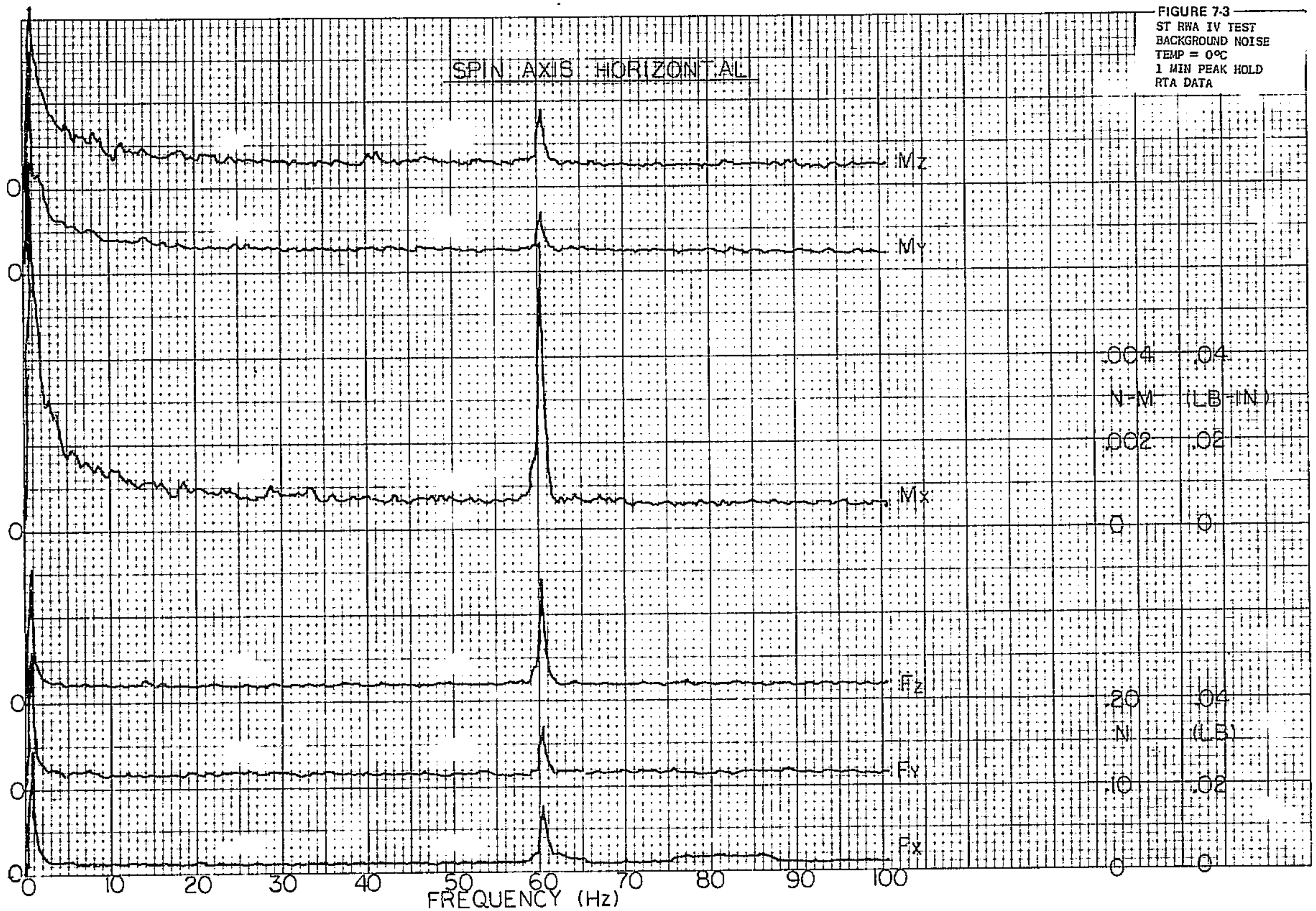
quartz load cells by the temperature difference between the mounting ring and the base plate. In lieu of static calibration data, background traces were obtained at both high and low temperatures prior to the operating runs. These traces are illustrated in Figure 7-2 for the 44°C test and Figure 7-3 for the 0°C test. When compared to the background traces at ambient temperature (Figure 5-10), any variation in static calibration should be observed. As noted, no significant variations occurred between the background noise levels at high and low temperatures and those at ambient temperature. Furthermore, the dynamic response of the EVMF would be unaffected by a variation in static scale factor permitting the acquisition of reliable data during ST RWA operating tests.

The initial temperature run was performed at 44°C with the ST RWA mounted on the EVMF under the thermal chamber. After reaching the stable temperature of 44°C, which occurred after 6 hours, a complete set of IV data from 1500 rpm to 100 rpm in 200 rpm steps for all three principle axes was taken and is illustrated in Figures 7-4 through 7-9. The equipment used and the method of taking data has been previously explained in Section 5.0. The disturbances noted appeared at the identical frequencies obtained during the ambient baseline tests. Table 7-1 summarizes the wheel speed magnitude at 1500 rpm operating speed for all the temperature tests performed.

Immediately after the 44°C run the chamber temperature was lowered to 0°C for the cold operating run. The chamber was operated overnight (16 hours) to stabilize at the cold temperature. The same EVMF data was taken as at the hot temperature and is illustrated in Figures 7-10 through 7-15. The disturbances at wheel speed were generally higher than previous EVMF data but still well below the target vibration levels. The greatest increase was noted on the moment about the Y or trunnion axis, an indication of dynamic balance shift. Static balance as indicated by the force levels along the X and Y axes was unchanged. Table 7-1 illustrates the levels attained at 25 Hz for this test. The 2X wheel speed disturbance on the moments about the spin axis is on the order of .0045 N-M (.040 lb-in.) for cogging torque. This level remains constant over the operating speed range.

SPIN AXIS HORIZONTAL
FIGURE 7-2
ST RWA IV TEST
BACKGROUND NOISE
TEMP = 44°C
1 MIN PEAK HOLD
RTA DATA
Mz
My
Mx
Fz
Fy
Fx
.004 .04
N-M (LB-IN)
.002 .02
0 0
.20 .04
N (LB)
.10 .02
0 0
0 10 20 30 40 50 60 70 80 90 100
FREQUENCY (Hz)
31297

FIGURE 7-3
ST RWA IV TEST
BACKGROUND NOISE
TEMP = 0°C
1 MIN PEAK HOLD
RTA DATA



31298

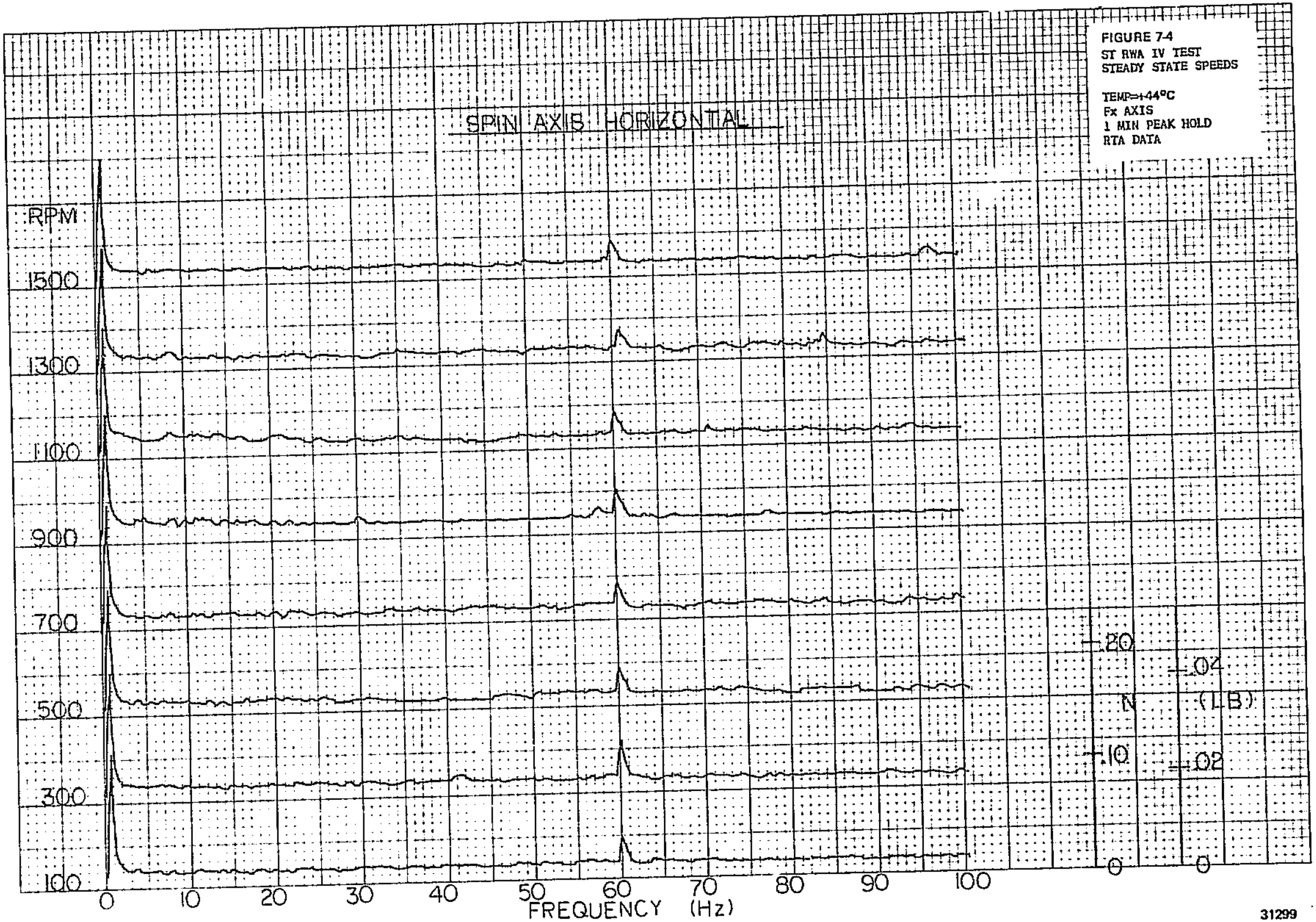


FIGURE 7-4
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
Fx AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
.04
N
(LB)
.10
.02
0
0

31299

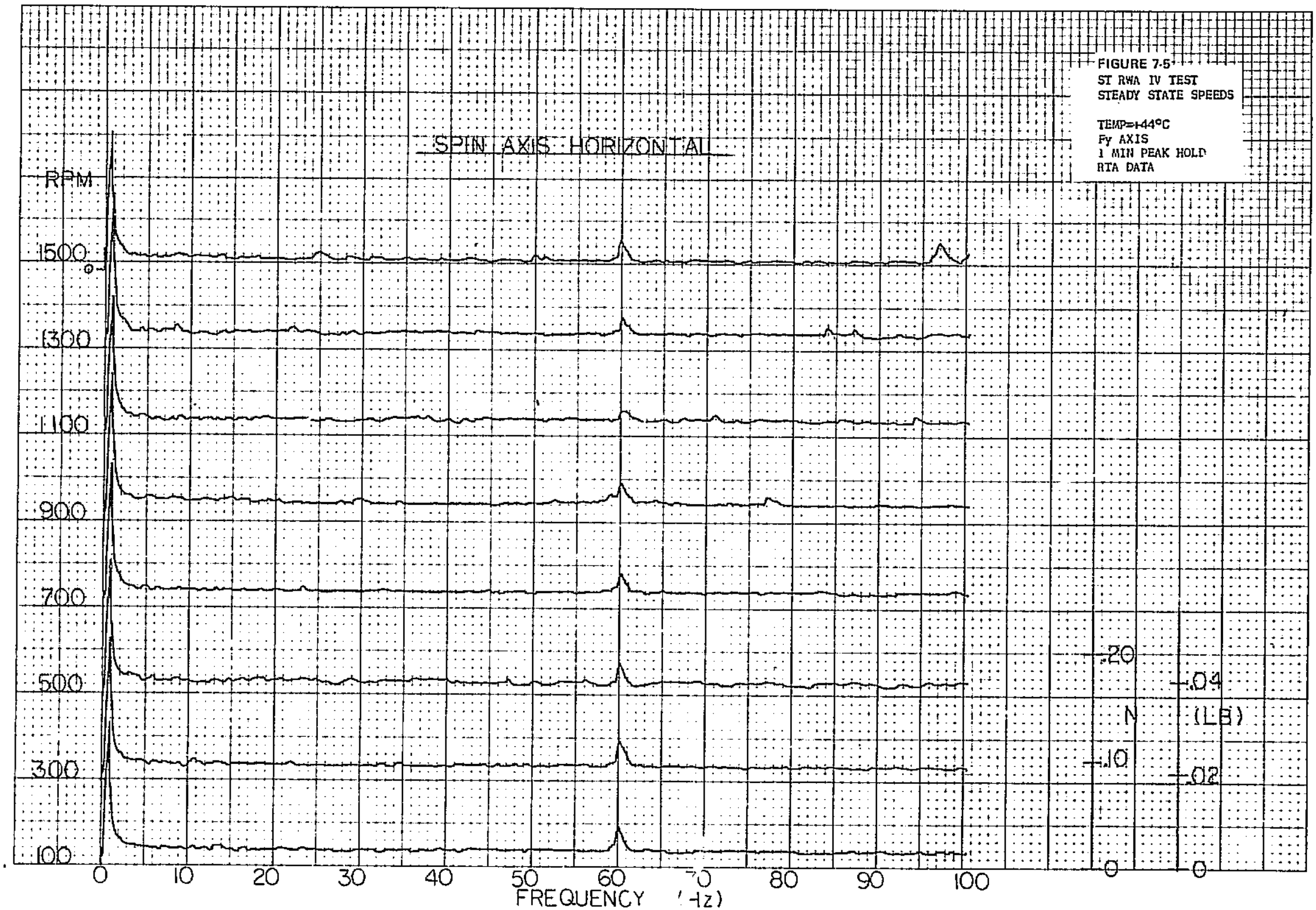


FIGURE 7-5
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
Fy AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
N
.10
0
.04
(LB)
.02
0

31300

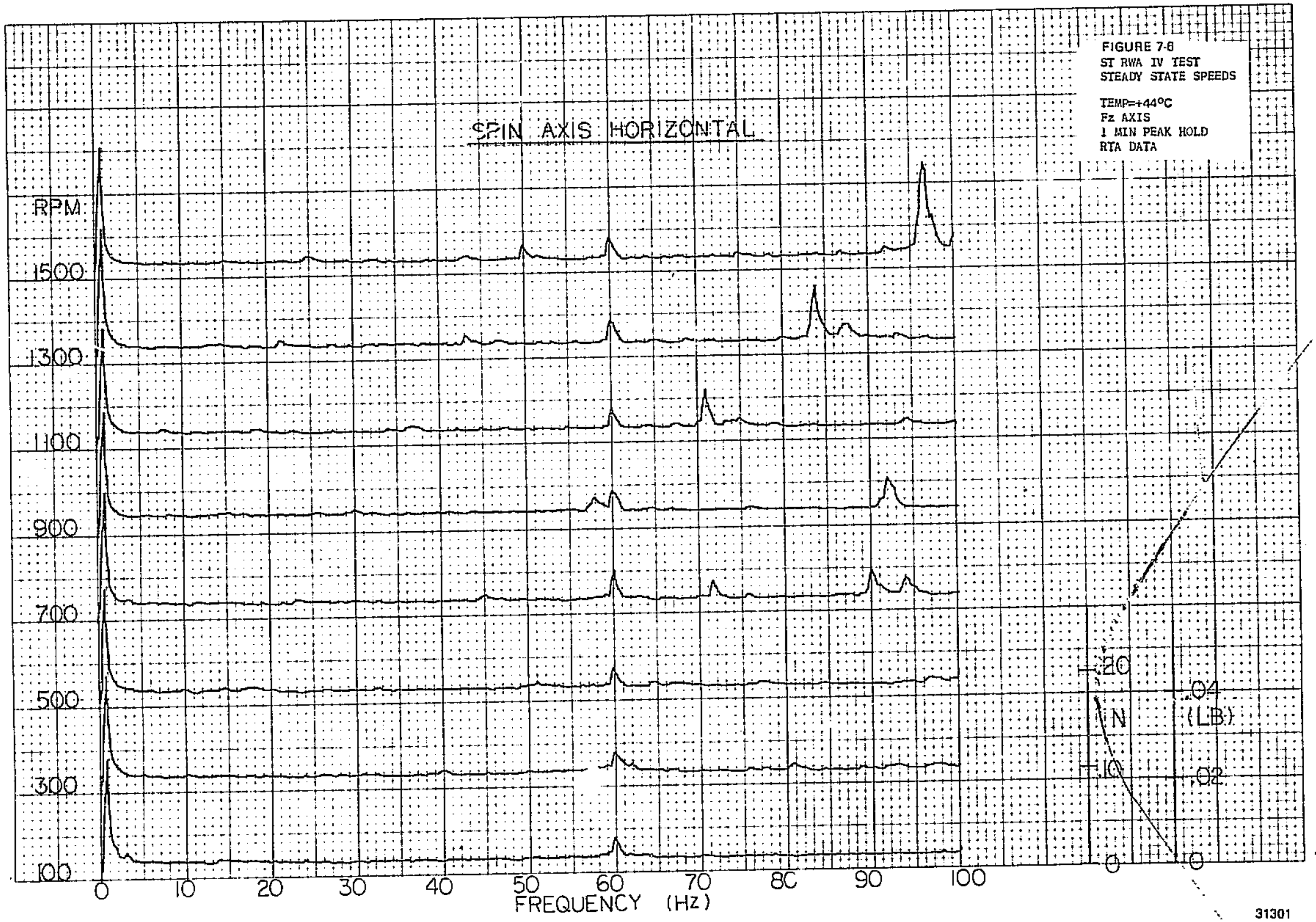


FIGURE 7-8
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
Fz AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
N
.10
0
.04
(LB)
.02
0
31301

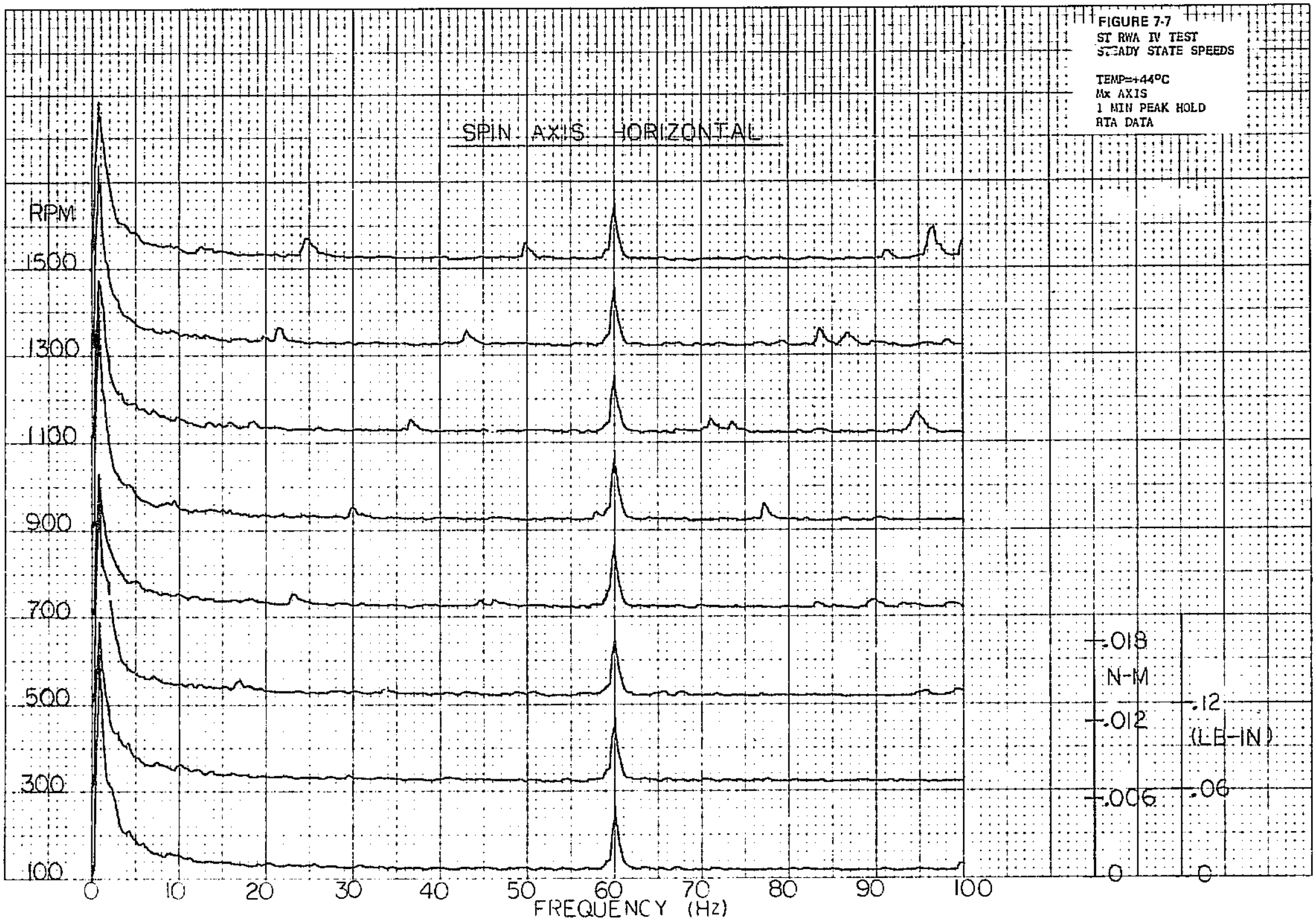


FIGURE 7-7
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
Mx AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.018
N-M
.012
.006
0
.12
(LB-IN)
.06
0

30302

FIGURE 7-8
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
My AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.004
.002
0
N-M
.04
.02
0
(LB-IN)

31303

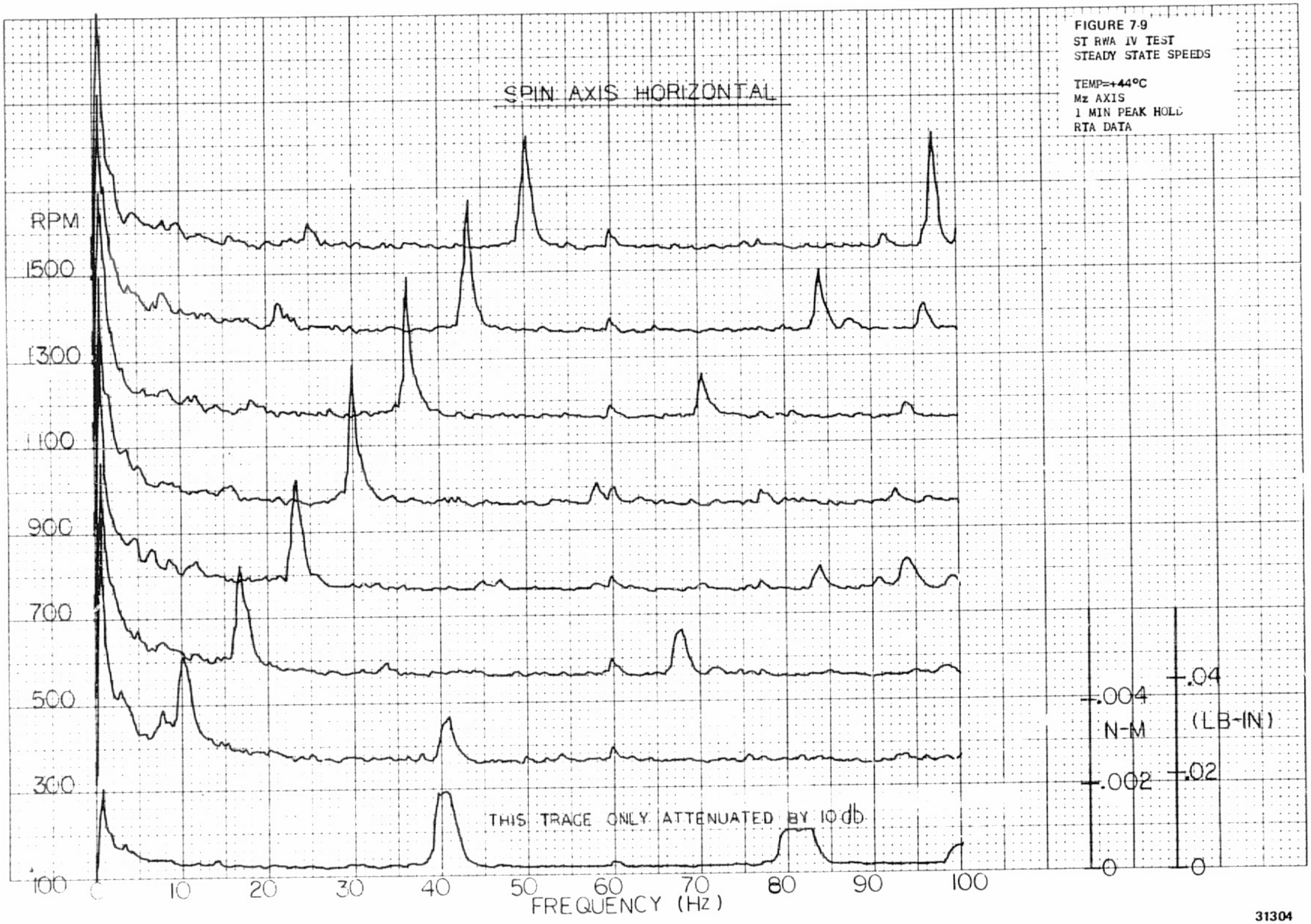


FIGURE 7-9
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP=+44°C
Mz AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
THIS TRACE ONLY ATTENUATED BY 10 db
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.004
N-M
.002
0
.04
(LB-IN)
.02
0

31304

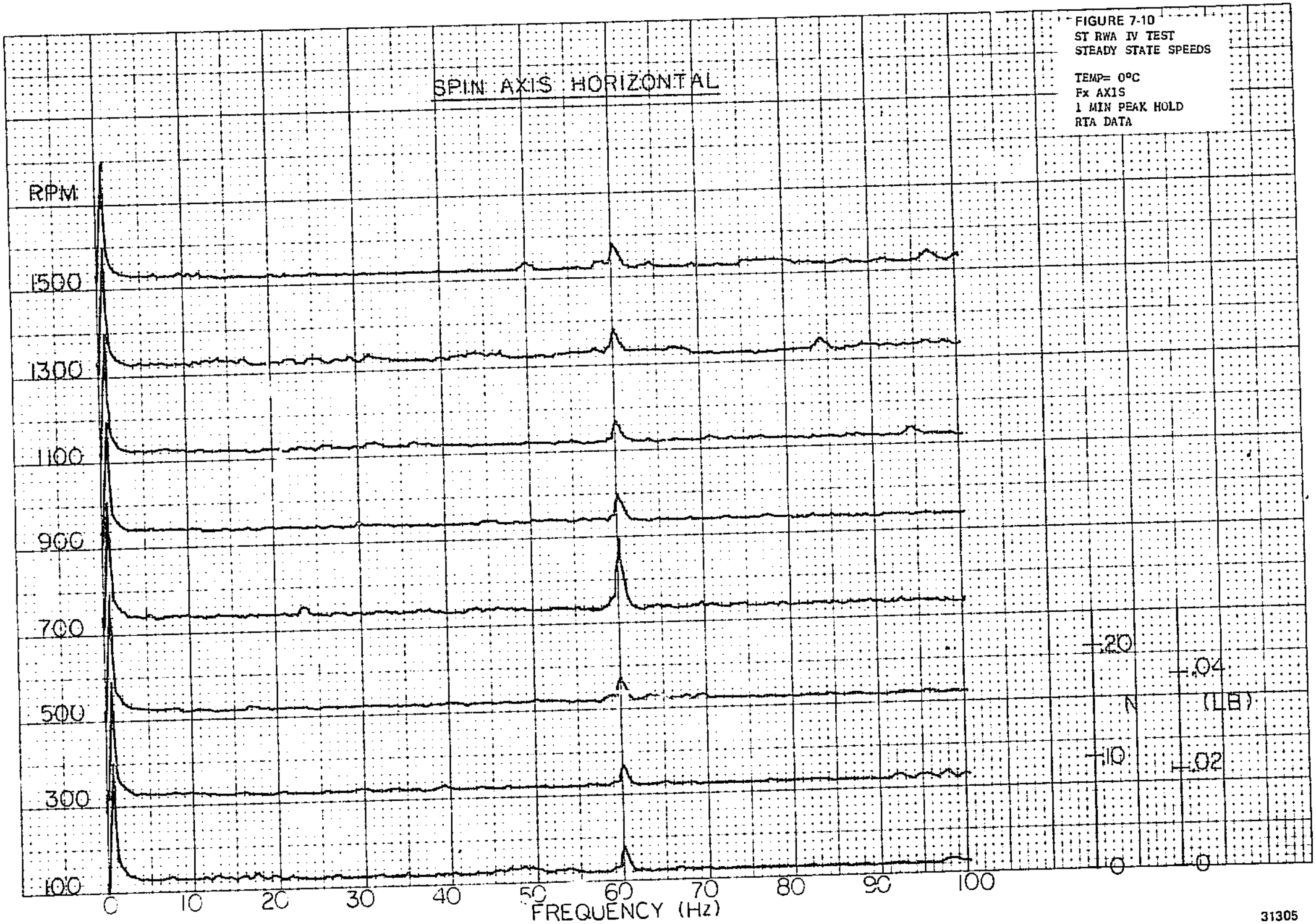


FIGURE 7-10
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
Fx AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
.10
0
N
.04
.02
0
(LB)

31305

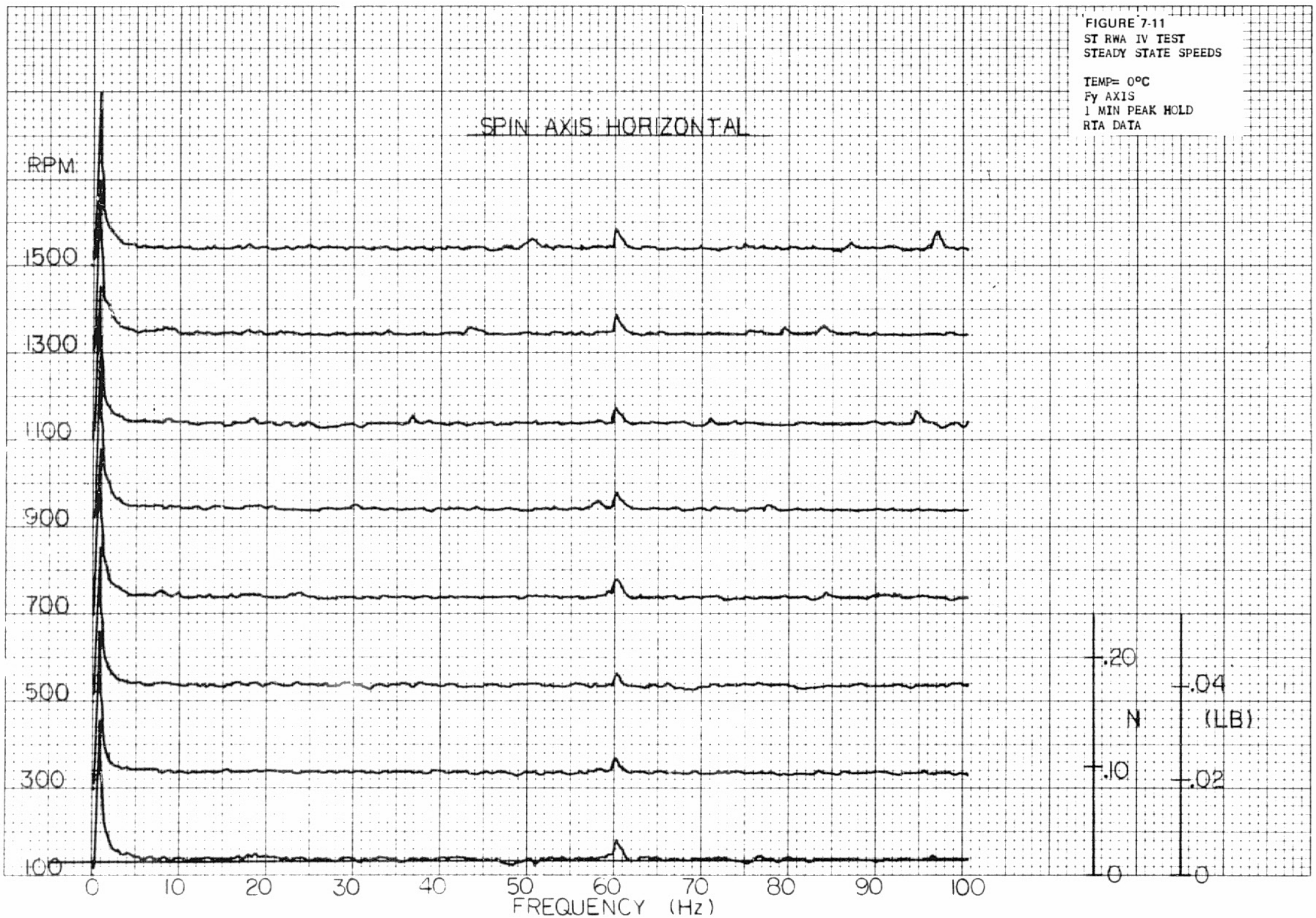


FIGURE 7-11
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
Fy AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
.10
0
N
.04
.02
0
(LB)

31306

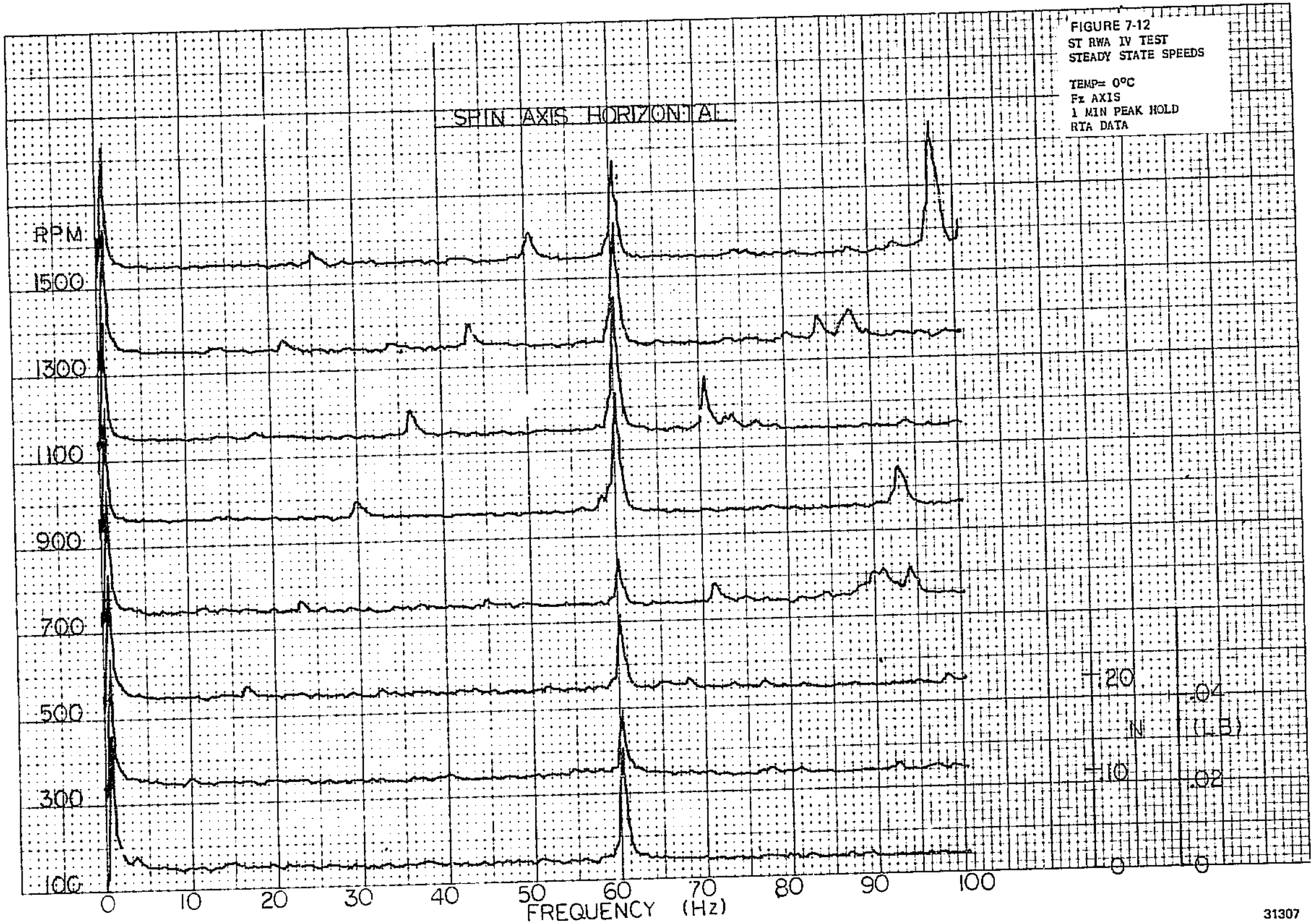


FIGURE 7-12
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
Fz AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
20
10
0
N
.04
.02
0
(LB)

31307

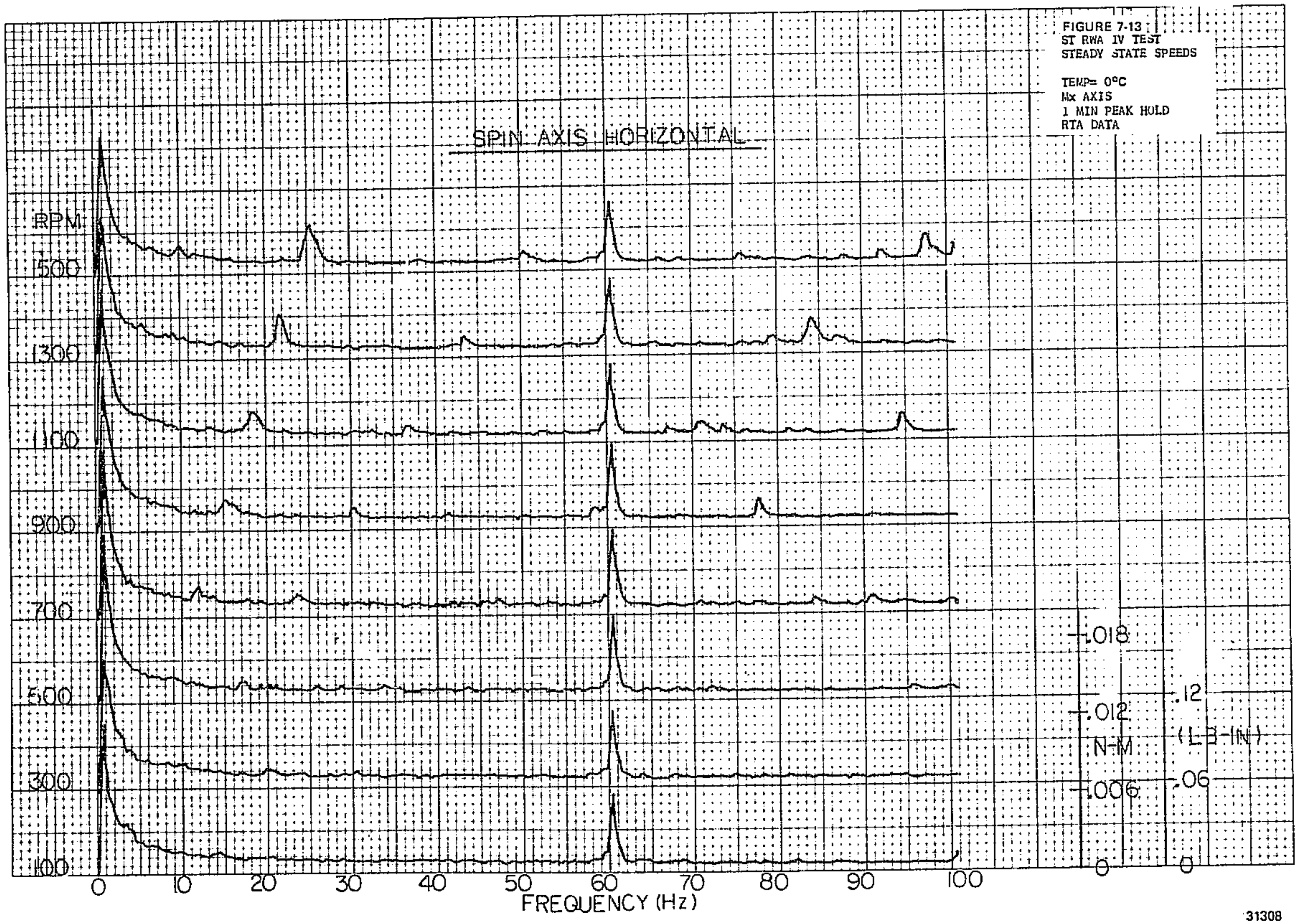


FIGURE 7-13
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
Mx AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.018
.012
N-M
.006
0
.12
(LB-IN)
.06
0
31308

FIGURE 7-14
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
My AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (HZ)
.004
.002
0
N-M
.04
.02
0
(LB-IN)

31309

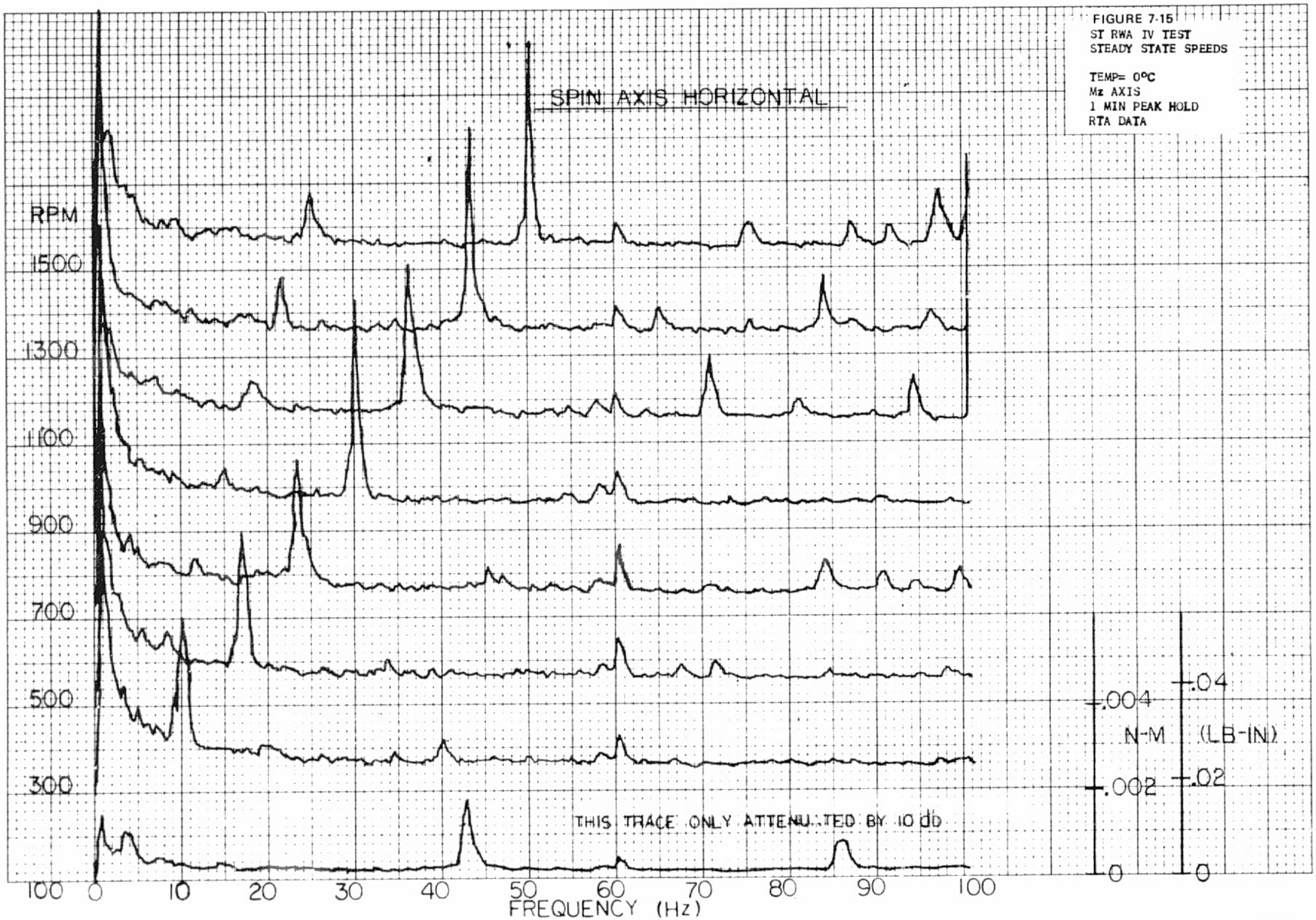


FIGURE 7-15
ST RWA IV TEST
STEADY STATE SPEEDS
TEMP= 0°C
Mz AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
THIS TRACE ONLY ATTENUATED BY 10 db
.004
.002
0
N-M
.04
.02
0
(LB-IN)
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31310

TABLE 7-1

25-HZ AMPLITUDES OF ST RWA IV DATA

Test Condition	F_x	F_y	F_z	M_x	M_y	M_z
	Newton (pound)			Newton-Meter (Pound-Inch)		
Ambient Baseline	.0044 (.0010)	.0067 (.0015)	.0133 (.0030)	.0005 (.0042)	.0007 (.0062)	.0005 (.0047)
Unit at 44°C	.0040 (.0009)	.0080 (.0018)	.0053 (.0012)	.0013 (.0114)	.0002 (.0022)	.0005 (.0045)
Unit at 0°C	.0022 (.0005)	.0040 (.0009)	.0116 (.0026)	.0003 (.0264)	.0022 (.0189)	.0011 (.0095)
Post 60°C Storage	.0062 (.0014)	.0129 (.0029)	.0205 (.0046)	.0014 (.0120)	.0021 (.0188)	.0010 (.0091)
Baseline Before -35°C Test	.0133 (.0030)	.0165 (.0037)	.0080 (.0018)	.0059 (.052)	.0018 (.0158)	.0049 (.0438)
Post -35°C Storage	.0133 (.0030)	.0285 (.0064)	.0133 (.0030)	.0053 (.0466)	.0042 (.0370)	.0008 (.0069)

The third test in this temperature control series followed immediately and consisted of storing the unit in the thermal vacuum chamber for 16 hours at 60°C and a pressure of 1.5×10^{-4} torr. (The ST RWA was not operated at this temperature extreme). The ST RWA was then slowly brought back to ambient conditions and placed on the EVMF for an emitted vibration run with results illustrated in Figures 7-16 and 7-17. Only the 1500 rpm data for the six axes was recorded; the results are presented in Table 7-1 for the 25-Hz disturbance. Compared to the data immediately preceding this run, i.e., the 0°C operational run, the 25 Hz amplitudes on the moment axes have all decreased while the force axes amplitudes have all increased. The 2X wheel speed on the moments about the spin axis was recorded as .0054 N-M (.0482 lb-in.). No other unusual disturbances were noted.

The -35°C storage test was performed after vibration exposure. Table 7-1 presents both the pre-storage run data (Figures 7-18 through 7-23) and the IV data, after the unit was exposed to -35°C for 16 hours. The thermal vacuum chamber was unavailable for this test so room air was present about the evacuated unit when stored at -35°C. On return to ambient temperature

FIGURE 7-16
ST RWA IV TEST
STEADY STATE SPEEDS
POST 60°C STORAGE RUN
WHEEL SPEED = 1500RPM
1 MIN PEAK HOLD
RTA DATA
Fz
Fy
Fx
0
0
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
.20
N
.10
0
.04
(LB)
.02
0

31311


FIGURE 7-17
ST RWA IV TEST
STEADY STATE SPEEDS
POST 60°C STORAGE RUN
WHEEL SPEED = 1500RPM
1 MIN PEAK HOLD
RTA DATA
Mz
My
Mx
THIS TRACE ONLY ATTENUATED
BY 10 db
.004
.04
N-M
(LB-IN)
.002
.02
0
0
0
0
10
20
30
40
50
60
70
80
90
100
0
0

31312

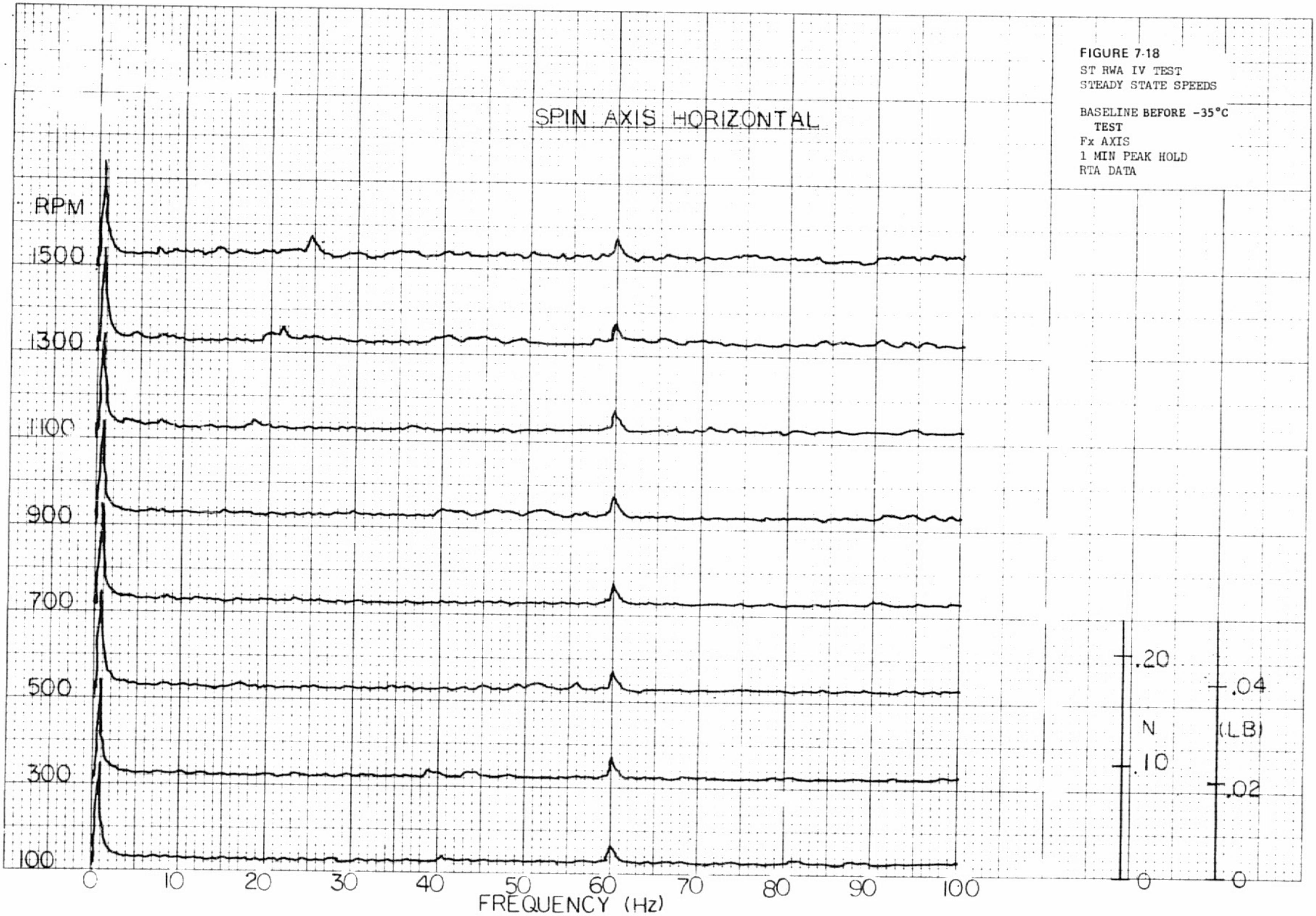


FIGURE 7-18
ST RWA IV TEST
STEADY STATE SPEEDS

BASELINE BEFORE -35°C
TEST
Fx AXIS
1 MIN PEAK HOLD
RTA DATA

31260

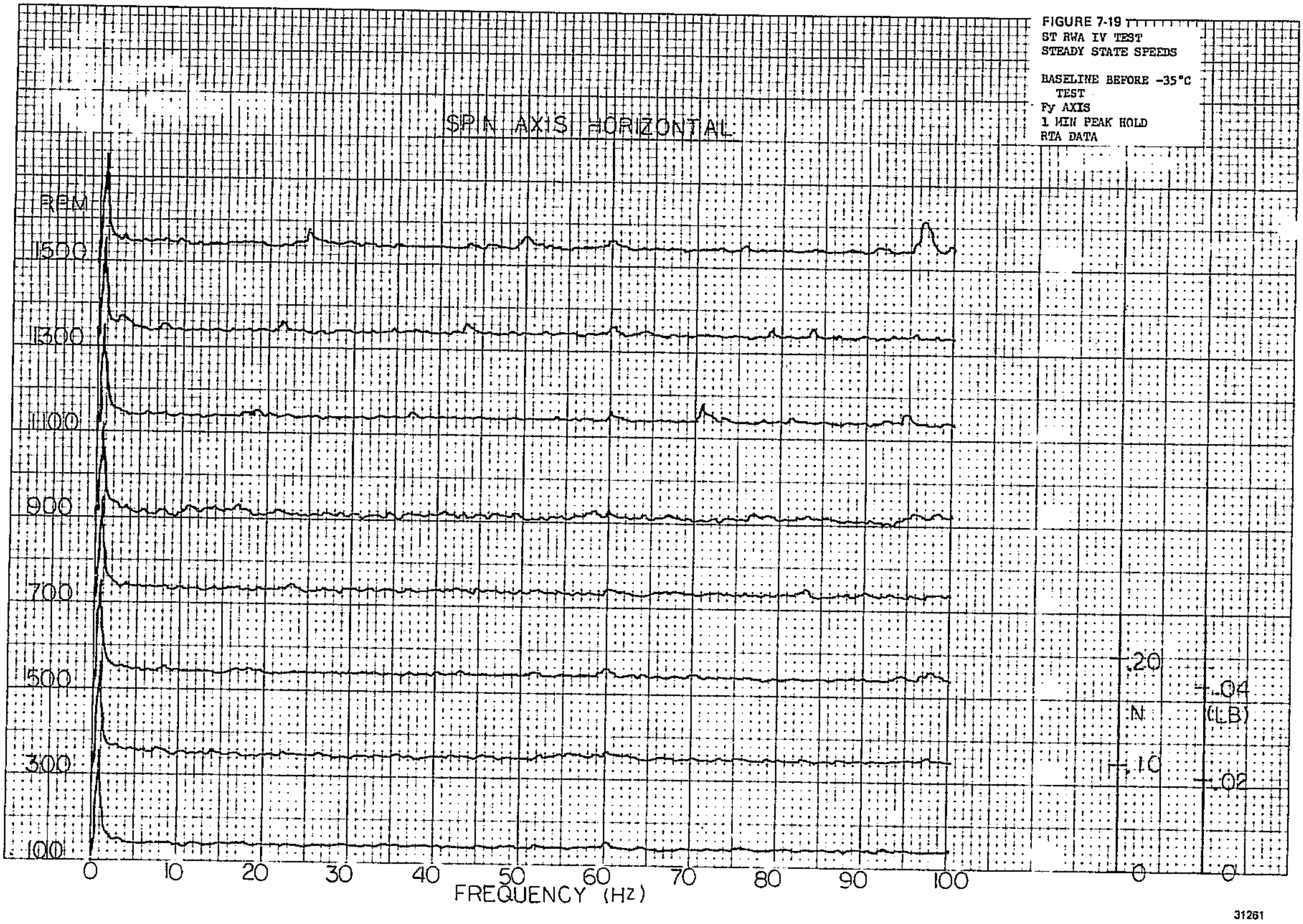


FIGURE 7-19
ST RWA IV TEST
STEADY STATE SPEEDS
BASELINE BEFORE -35°C TEST
Fy AXIS
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
RPM
1500
1300
1100
900
700
500
300
100
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (HZ)
.20
N
.10
0
.04
(LB)
.02
0
31261

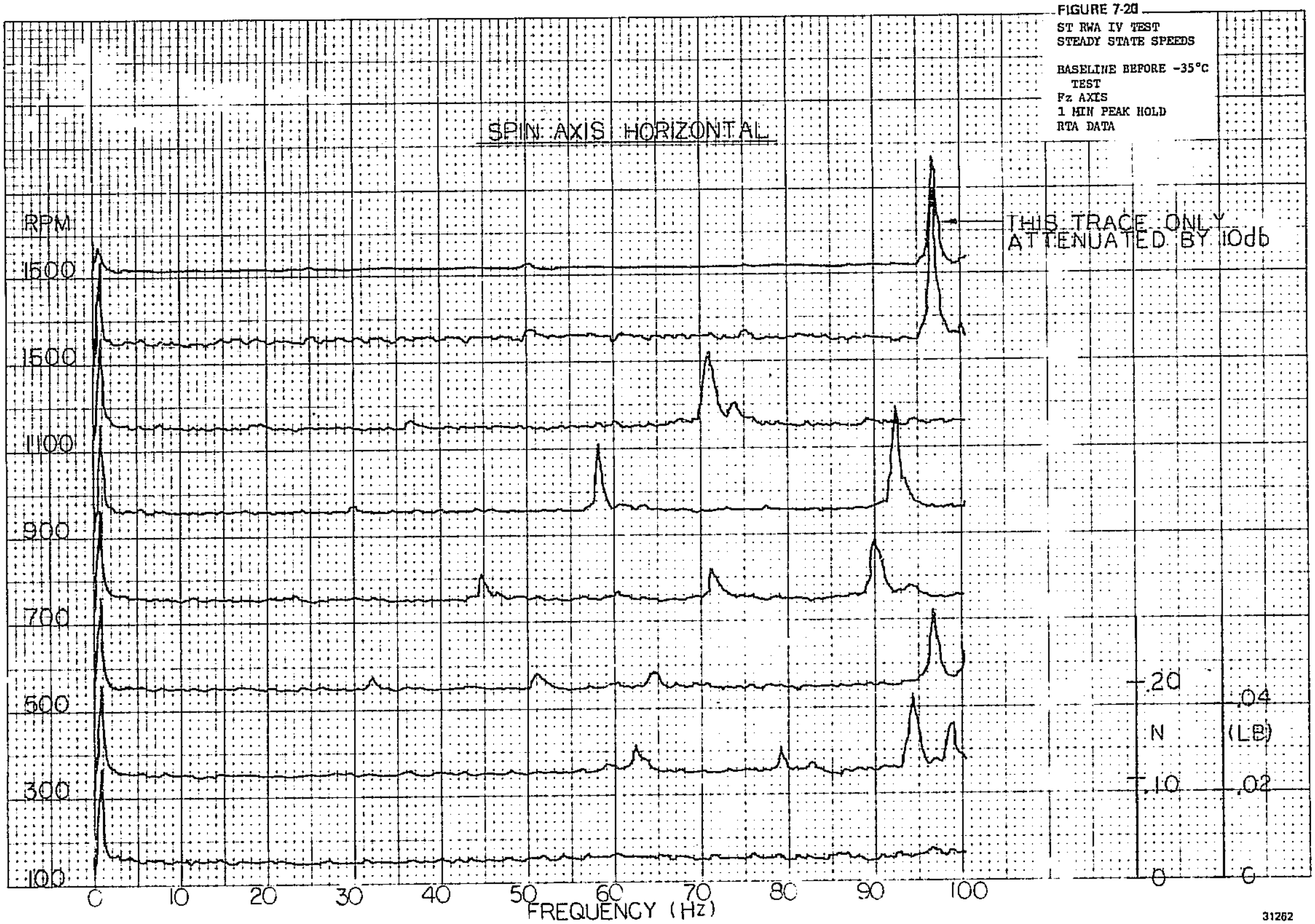


FIGURE 7-20
ST RWA IV TEST
STEADY STATE SPEEDS

BASELINE BEFORE -35°C
TEST
Fz AXIS
1 MIN PEAK HOLD
RTA DATA

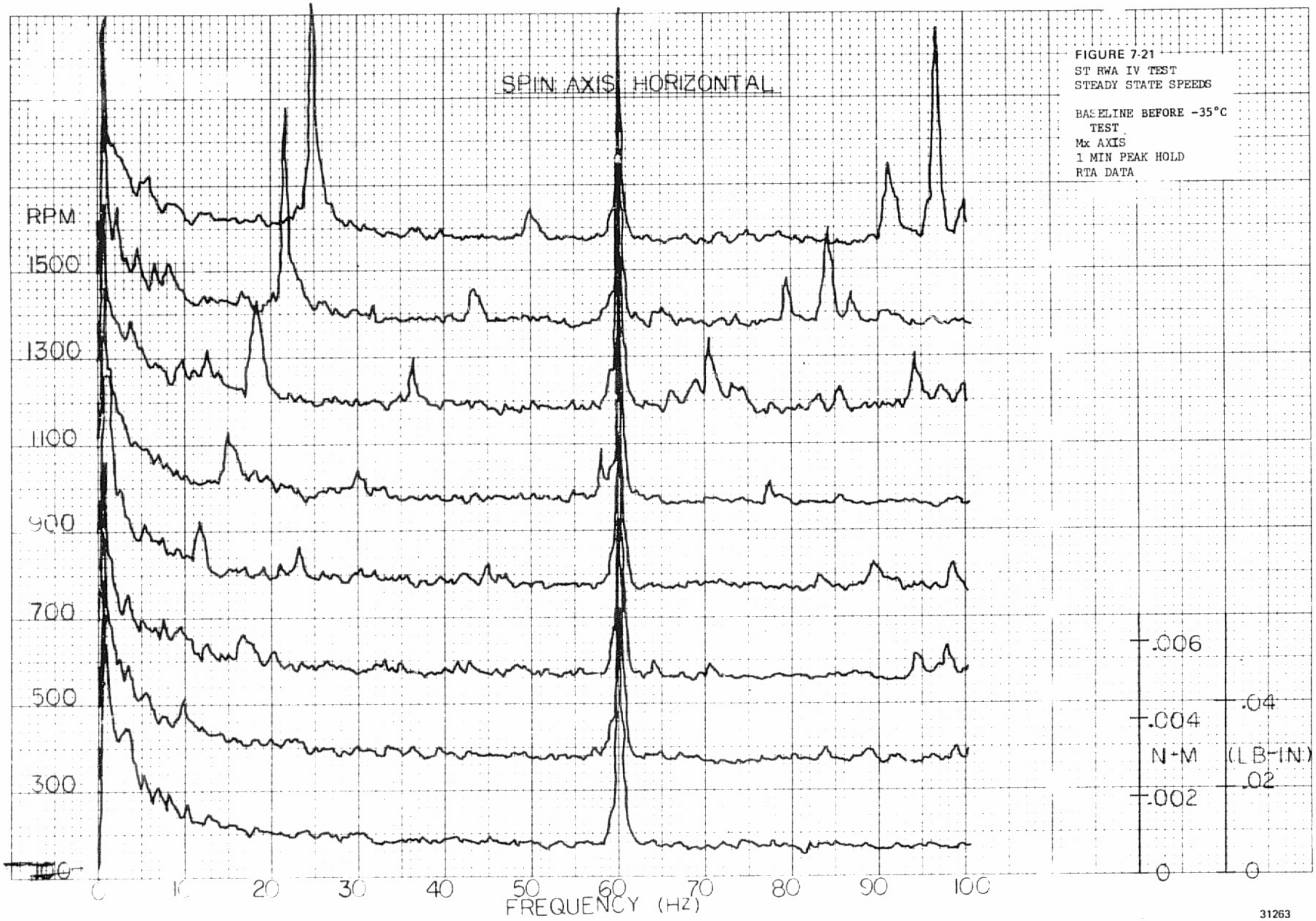


FIGURE 7-21
ST RWA IV TEST
STEADY STATE SPEEDS

BASELINE BEFORE -35°C
TEST
Mx AXIS
1 MIN PEAK HOLD
RTA DATA

31263

FIGURE 7-22
ST RWA IV TEST
STEADY STATE SPEEDS

BASELINE BEFORE -35°C TEST
My AXIS
1 MIN PEAK HOLD
RTA DATA

31264

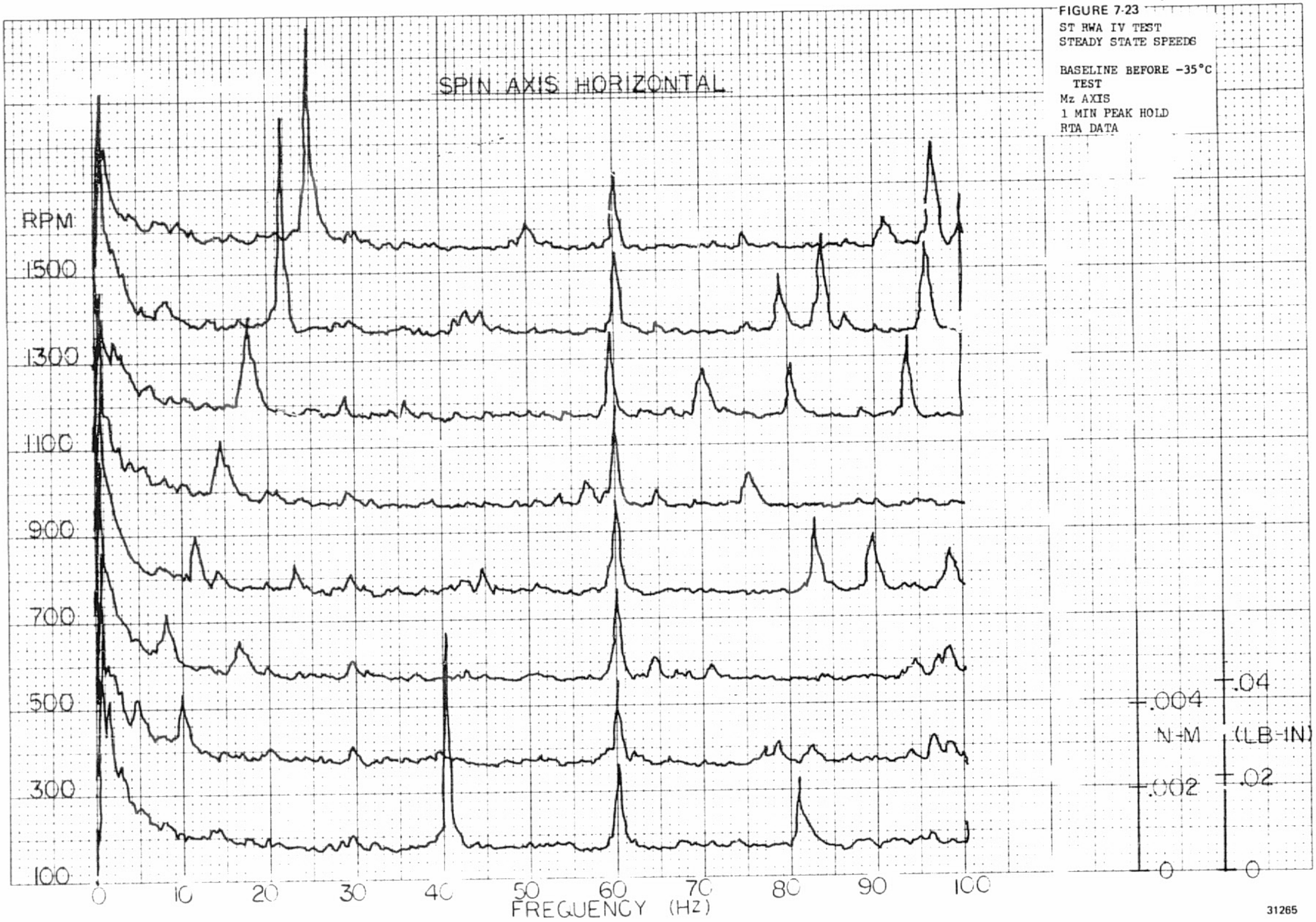


FIGURE 7-23
ST RWA IV TEST
STEADY STATE SPEEDS

BASELINE BEFORE −35°C TEST
Mz AXIS
1 MIN PEAK HOLD
RTA DATA

the air was heated to 50°C to remove any condensed moisture from the unit before the ST RWA stabilized at room temperature. The unit was then placed on the EVMF and the data of Figure 7-24 was produced. Only the 1500 rpm data was taken for the six principles axes. The largest disturbances occurred at 25 Hz, or wheel speed, on all three moment axes. The 2X wheel speed disturbance was at a reduced level for all data. No consistent change in force or moment amplitudes was noted indicating no significant degradation in emitted vibration had occurred.

In summary, it can be seen from Table 7-1 that over the nominal operating temperature range of 0°C to 44°C, some forces and moments reduced and the greatest increases are in Mx at 0°C, 5.8×10^{-4} N-m/°F (5×10^{-4} in.-lbf/°F), and in Fy at the high temperature, 3.5×10^{-5} N/°F (8×10^{-6} in.- lbf/°F).

FIGURE 7-24
ST RWA IV TEST
STEADY STATE SPEED
AFTER -35°C SOAK
WHEEL SPEED = 1500RPM
1 MIN PEAK HOLD
RTA DATA

31313

SECTION 8.0

VIBRATION TESTS

SECTION 8.0

VIBRATION TESTS

The ST RWA was exposed to a 3-axis random vibration shake and a sinusoidal resonance search along two axes from 5 to 2000 Hz. These tests were performed at General Dynamics in San Diego, California on a MBC-200 vibration exciter. EVMF data runs were performed on all six principle axes before and after the vibration exposure to observe the effects on emitted vibration performance of the ST RWA. Drag torque checks were perfomed to evaluate the bearing condition after vibration.

The random vibration exposure consisted of mounting the ST RWA unit, with adapter blocks, to a shaker and applying the random vibration levels of Figure 8-1 for a 90 second time period per axis. The random input was plotted as power spectral density input level versus frequency in Figure 8-1. The tolerance on the input level was held to ±.5 dB from 0 to 500 Hz and ±3 dB from 500 to 2000 Hz. The overall level was calculated to be 6.5 grms. The actual input levels were introduced through two control accelerometers located as shown in Figure 8-2. Accelerometer No. 1 controlled along the shake axis while accelerometer No. 2 controlled along the cross-axis to ensure actual input levels to the unit were not exceeded by fixture resonance.

The actual random vibration input levels recorded are illustrated in Figures 8-3 through 8-8. Two recordings were made for each axis, one on the shake axis and the other on the cross axis. The dotted lines on the graphs represent the tolerance envelope around the proposed power spectral density input levels. The recordings indicate wher control is transferred from one accelerometer to the other accelerometer to ensure full level input. The only anomaly appears on the X axis at the frequencies 500 to 650 Hz. No input was supplied at these frequencies for the 90 second duration of the test. However, the resonance search along this axis showed no resonance in this frequency range, therefore, a retest was not performed.

A sine input resonance search was also performed on the ST RWA in the X and Y axes prior to random vibration. The resonance search was from 5 Hz to

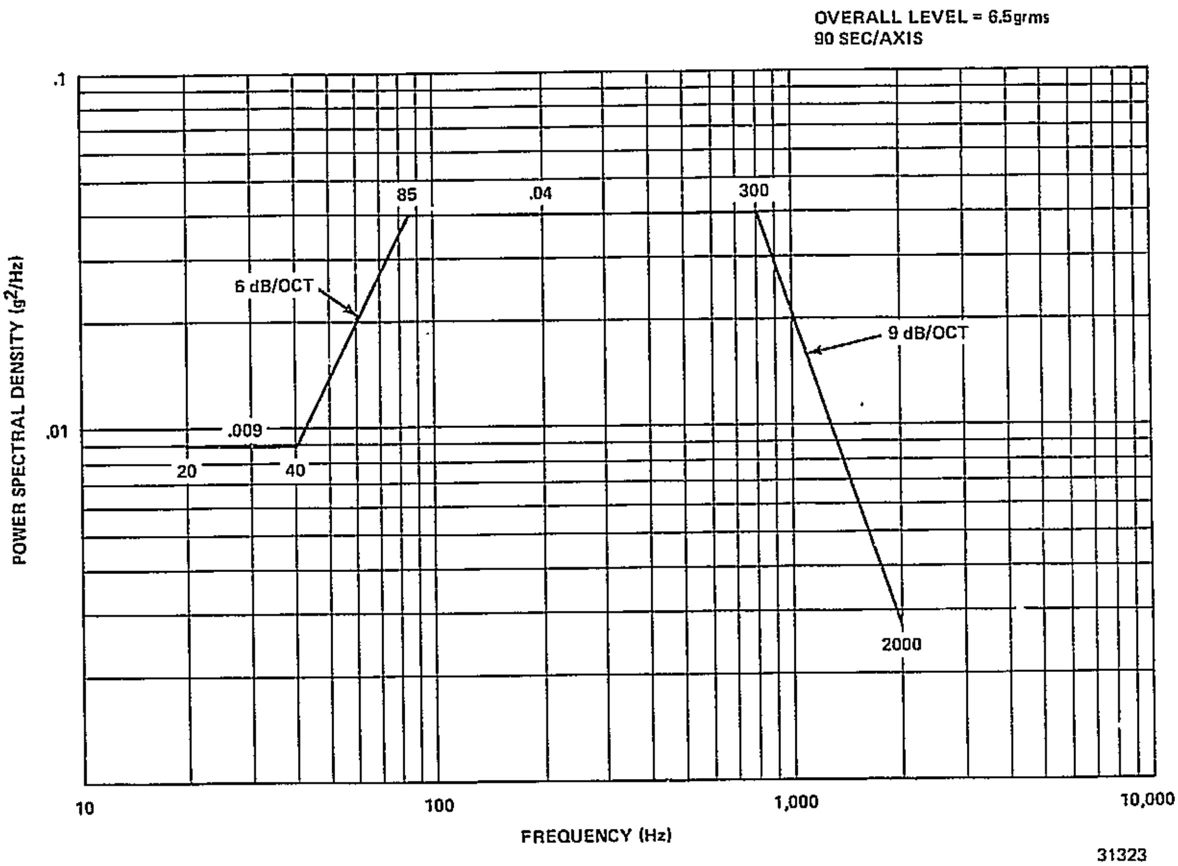


Figure 8-1
ST RWA Random Vibration Input Levels

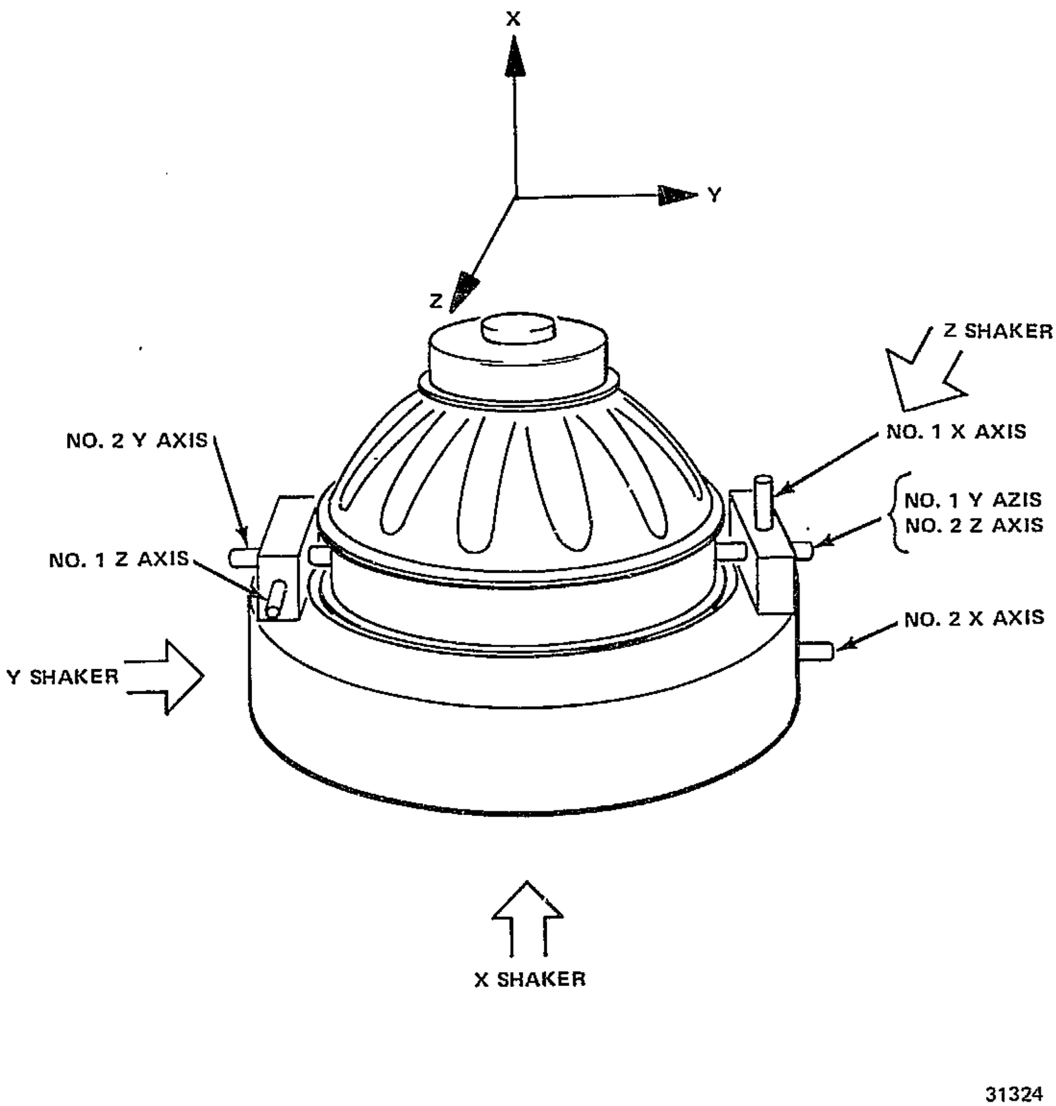


Figure 8-2
Control Accelerometer Locations for ST RWA Vibration Tests

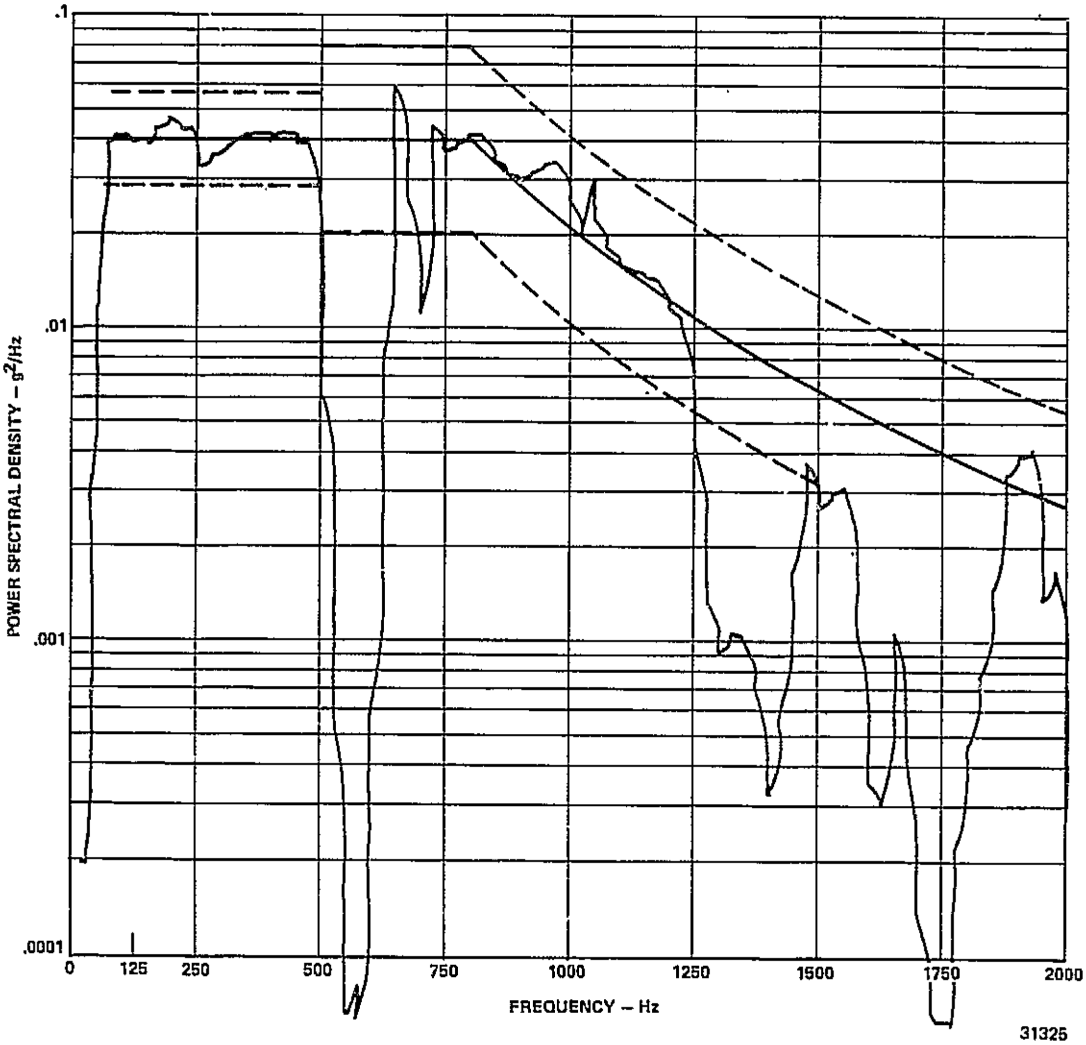


Figure 8-3
X Axis Inline Control
Accelerometer No. 1

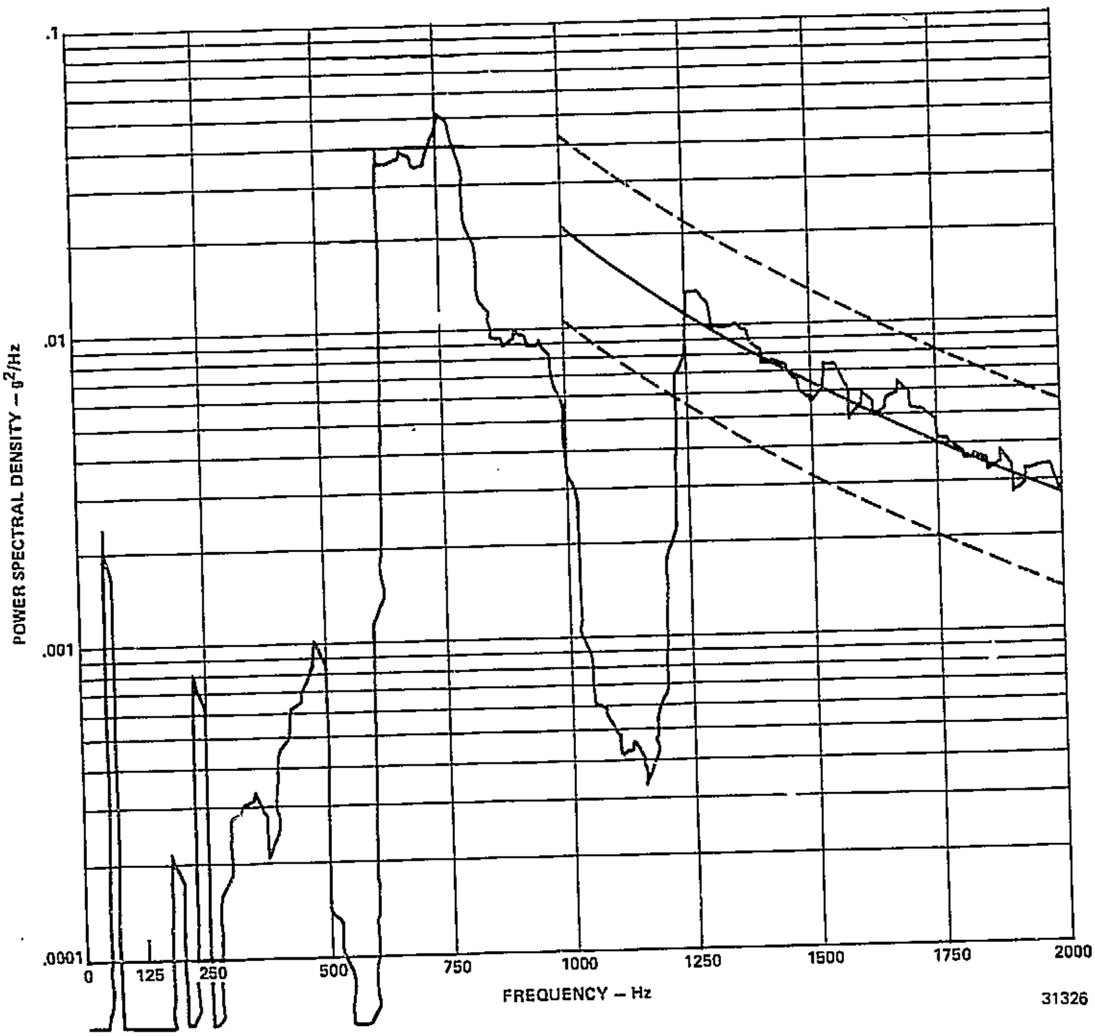


Figure 8-4
X Axis Cross Axis Control (Y Axis)
Accelerometer No.2

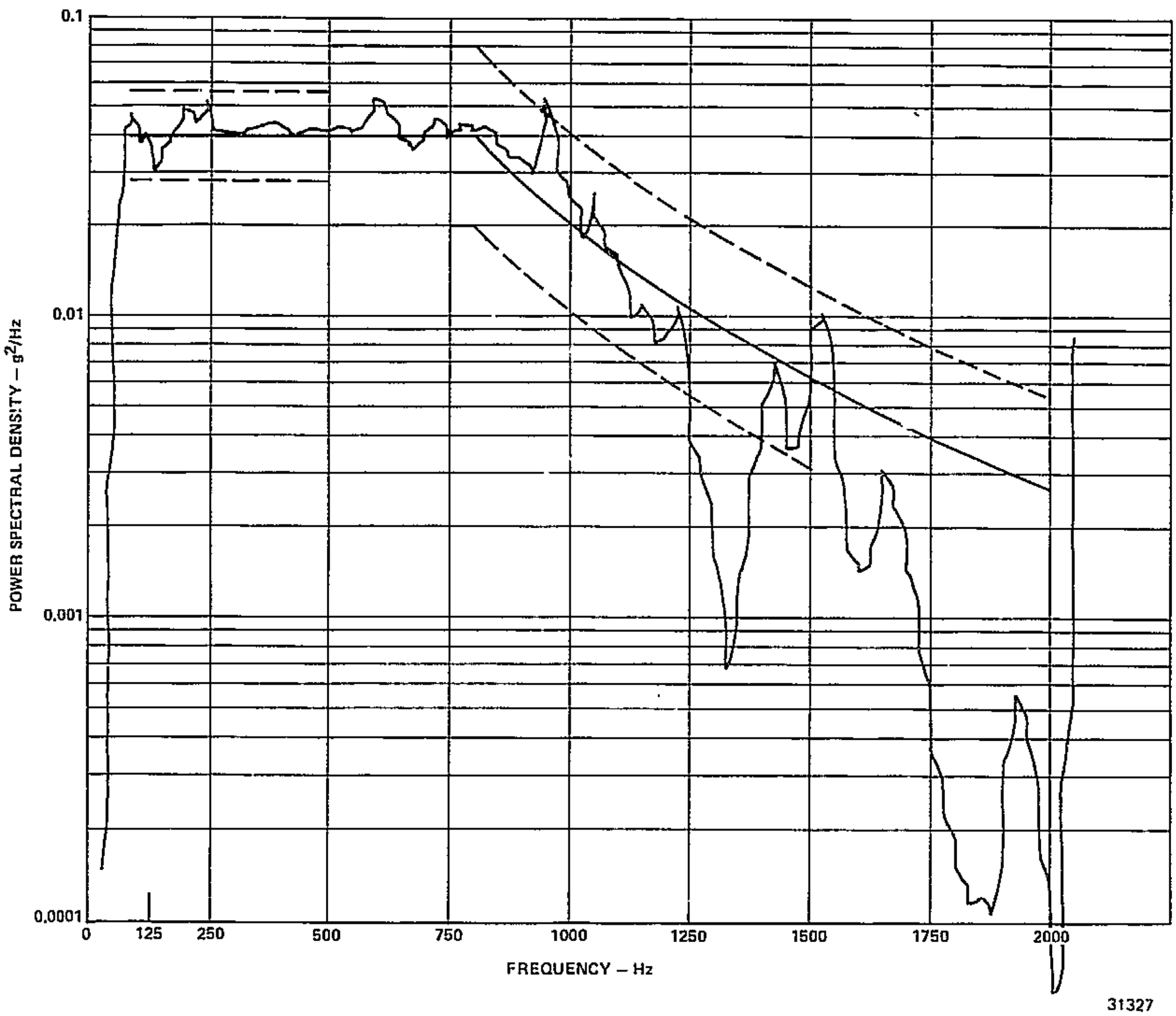


Figure 8-5
Y Axis Inline Control - Front
Accelerometer No. 1

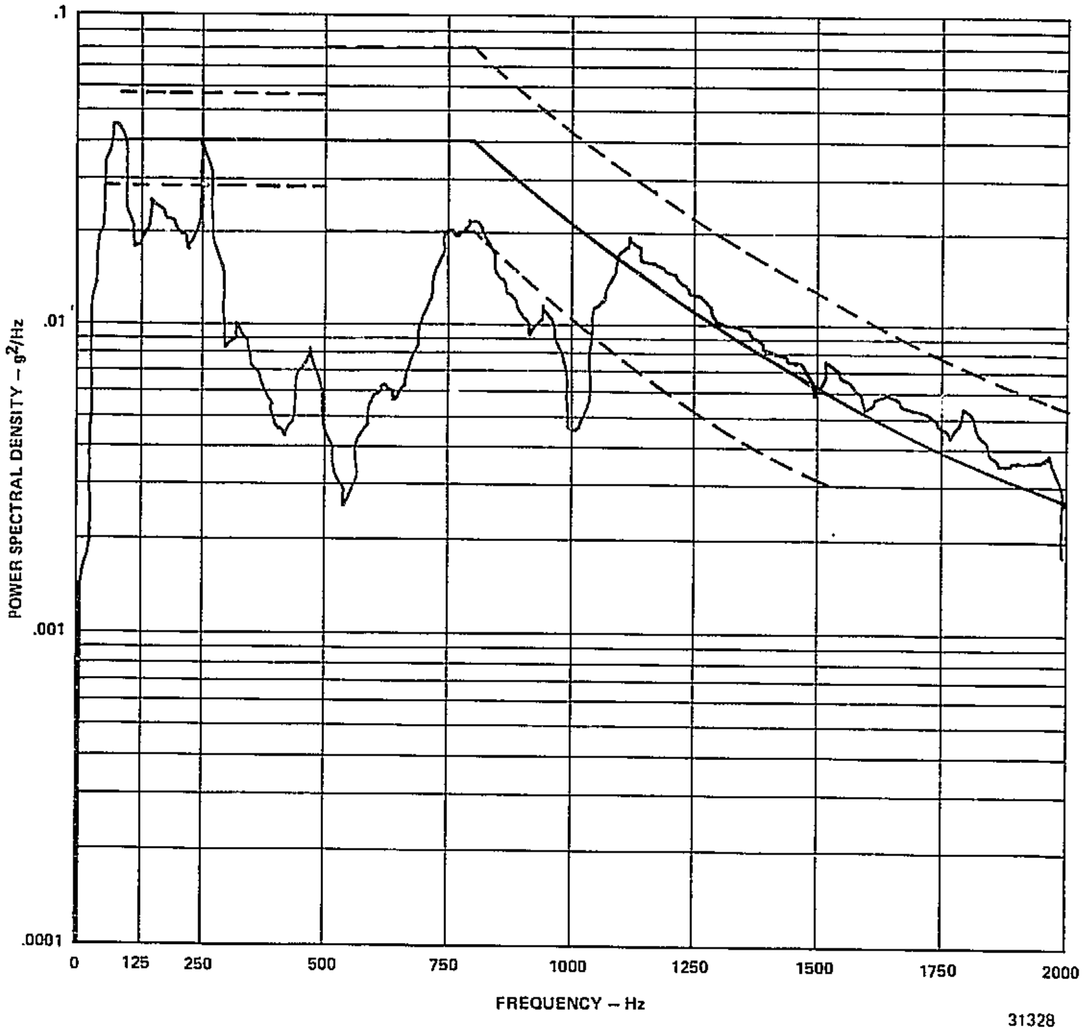


Figure 8-6
Y Axis Inline Control - Rear
Accelerometer No.2

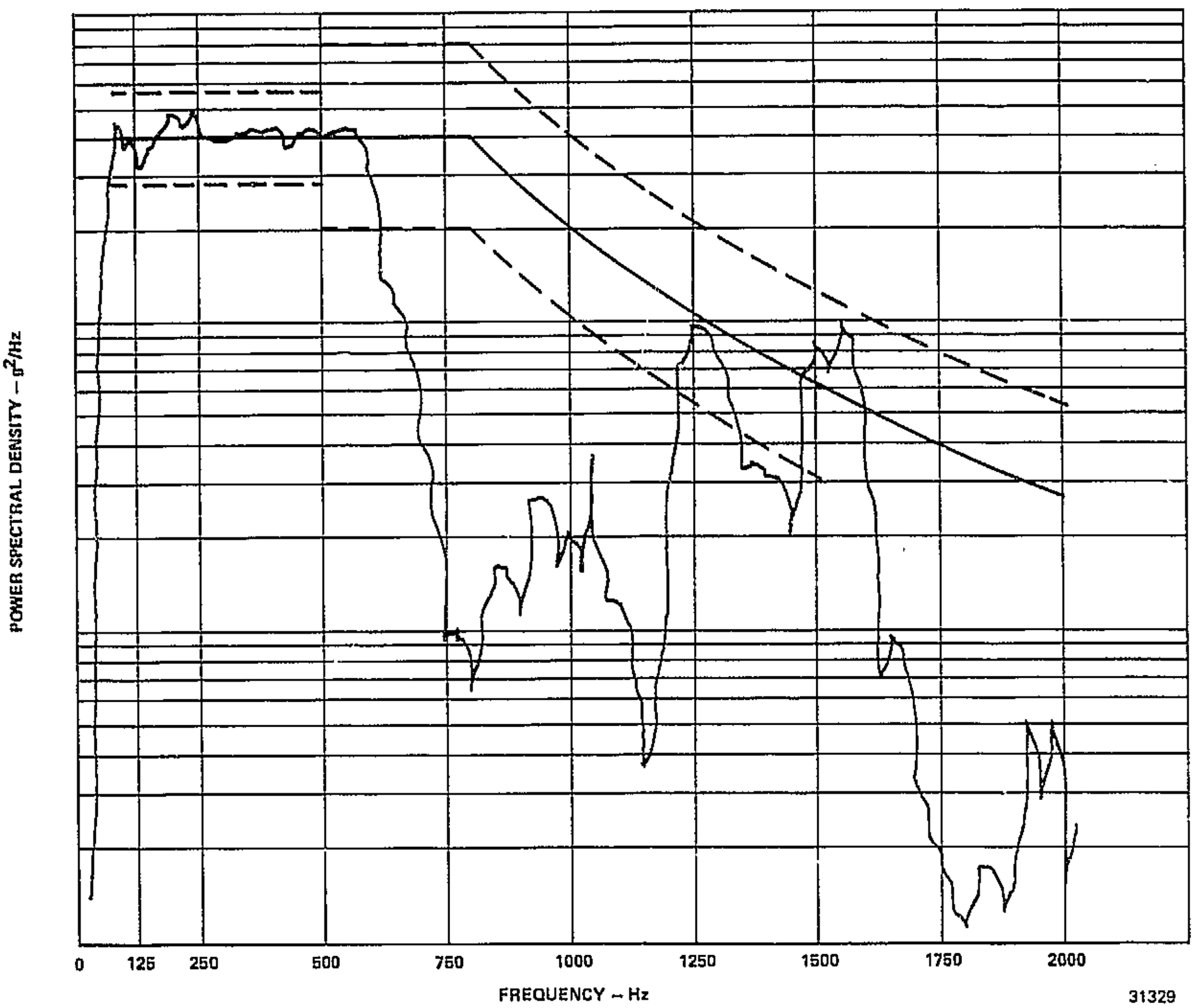


Figure 8-7
Z Axis Inline Control
Accelerometer No. 1

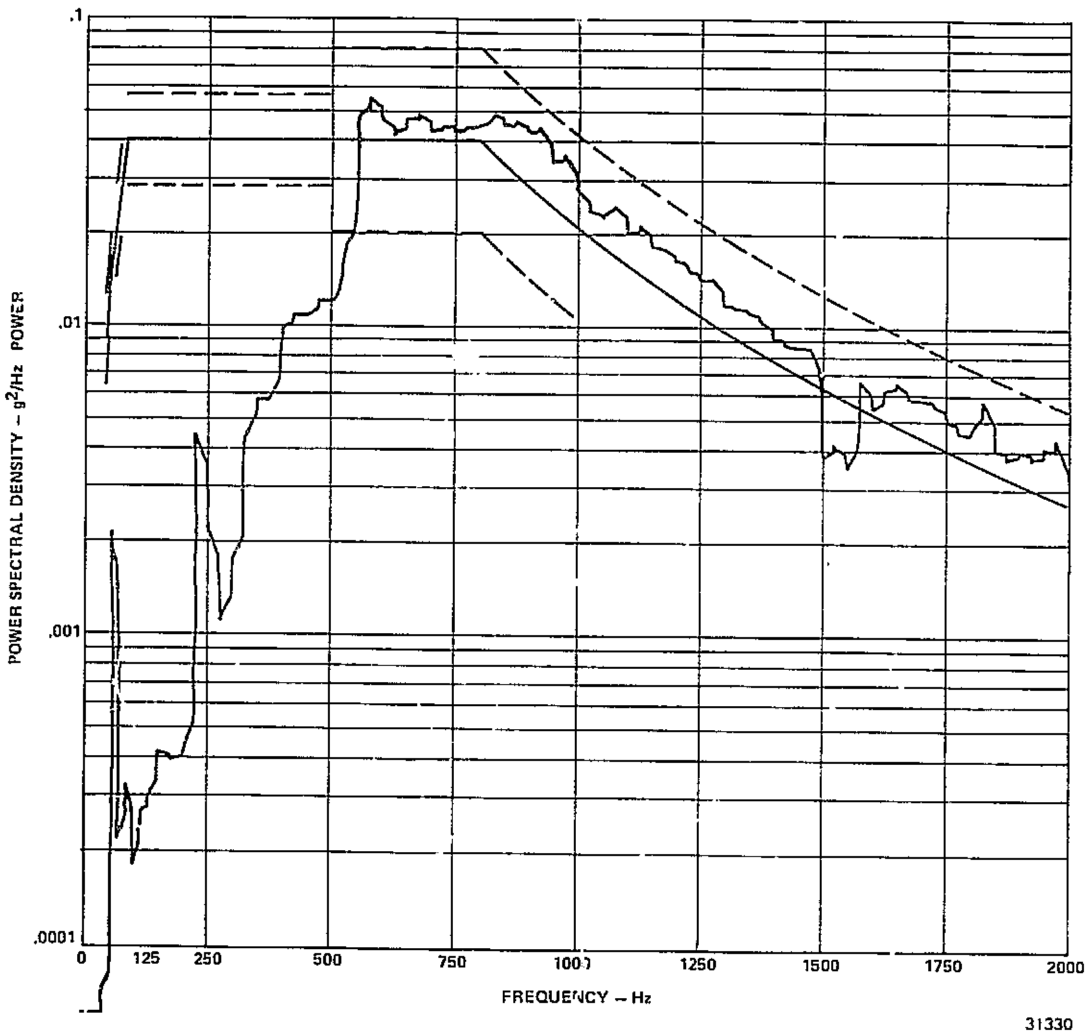


Figure 8-8
Z Axis Cross Axis Control (Y Axis)
Accelerometer No.2

2000 Hz with a sine input level of .25 grms at a sweep rate of 1 minute per octave. Two output accelerometers were located on the ST RWA in the locations noted in Figure 8-9, aligned along the shake axis in each test. The data from these accelerometers is summarized in Table 8-1 and is listed as amplification factors of the resonant peaks. The highest peak occurred at 350 Hz with a Q of 25. The peak was attributed to the spin motor stator mounting configuration. A key resonance occurred at 75 Hz along the spin axis with a Q = 1.65 due to the rotor resonanting on the bearing suspension system. Prior structural analysis showed a 5 to 1 amplification between the rotor mount and the accelerometer location providing an actual Q 10. The other resonances are summarized in Table 8-1.

A complete set of 3-axes EVMF data at steady state speeds from 100 rpm to 1500 rpm in 200 rpm steps was taken before and after exposure to the above vibration levels to determine the effects on the ST RWA emitted vibrations. The data is illustrated in Figures 8-10 through 8-17 for the pre-vibration test and Figures 8-18 through 8-25 for the post-vibration EVMF test. The principle disturbances which occurred at 25 Hz are summarized in Table 8-2 for a wheel speed of 1500 rpm.

The greatest emitted vibration level increases due to exposure to the 6.5 grms random input level are found (see Table 8-2) to be in F_y and M_z. F_y is the emitted force along the trunnion axis and attributable to a shift in rotor static unbalance. M_z is the measurement of emitted moment disturbances about the spin axis and is not attributable to either rotor unbalance, bearing anomalies, or spin motor anomalies. Disassembly of the RWA showed no apparent looseness or damage that would explain the change in M_z. However, the magnitude of the change in M_z would not necessarily warrant obvious internal damage.

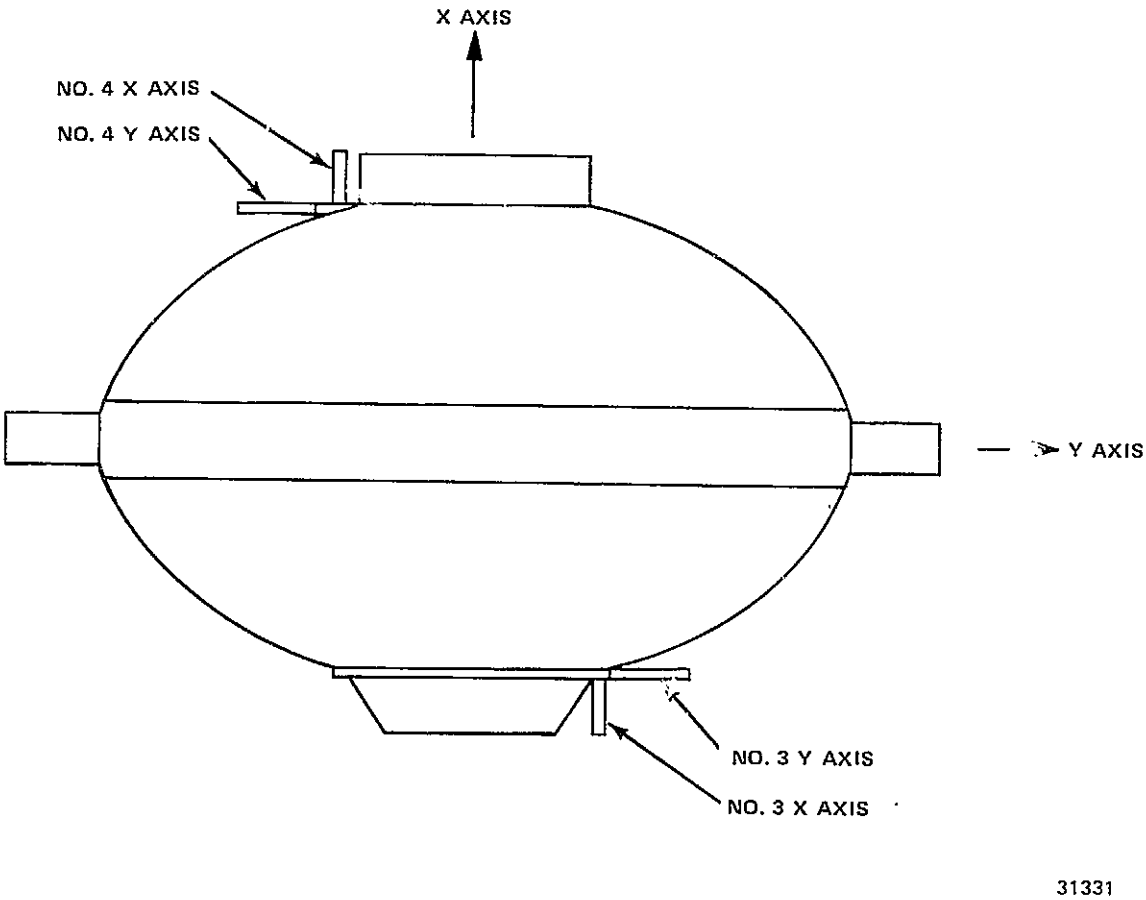
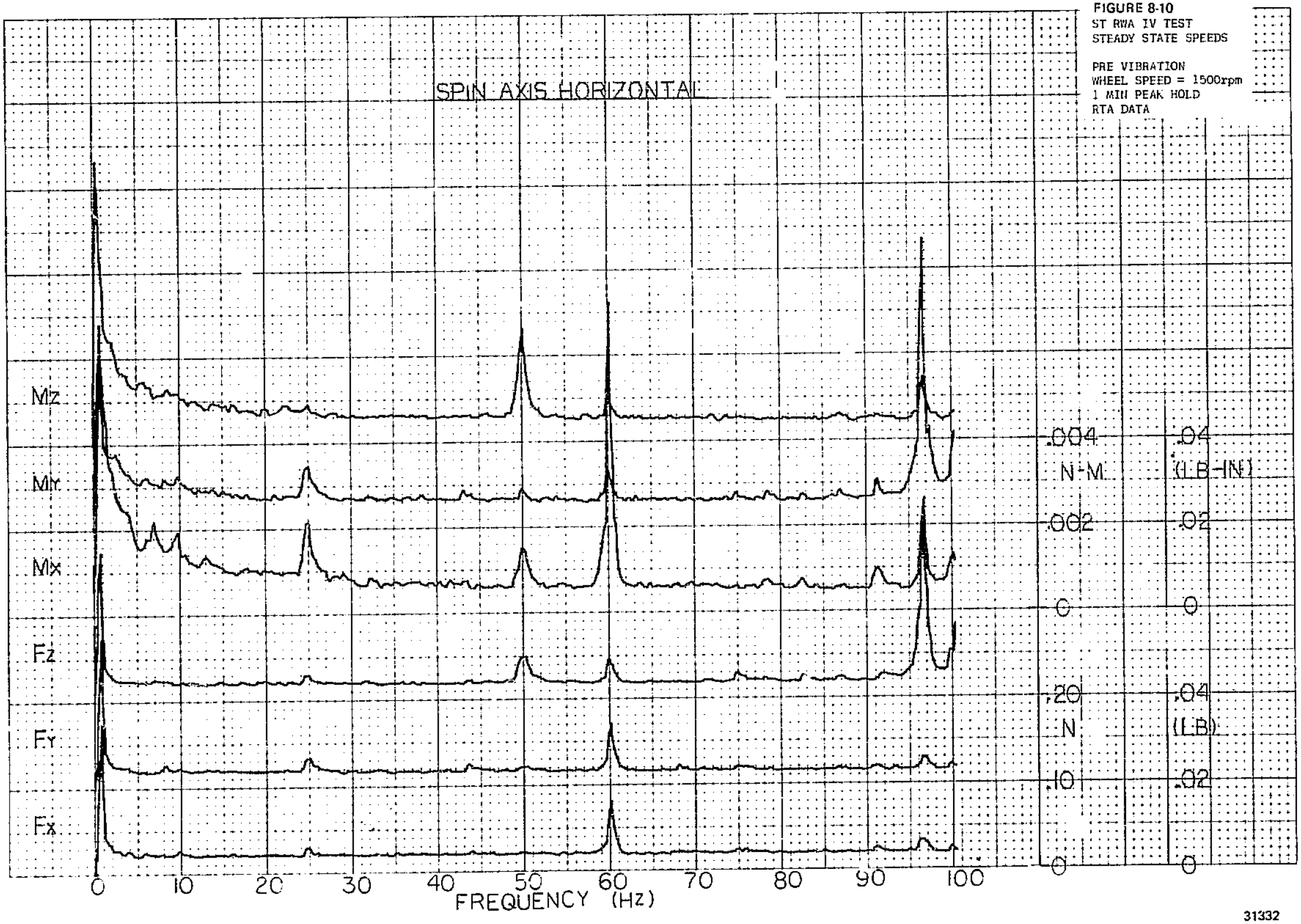


Figure 8-9
Output Accelerometer Locations for ST RWA Sine Search Tests

FIGURE 8-10
ST RWA IV TEST
STEADY STATE SPEEDS

PRE VIBRATION
WHEEL SPEED = 1500rpm
1 MIN PEAK HOLD
RTA DATA



31332

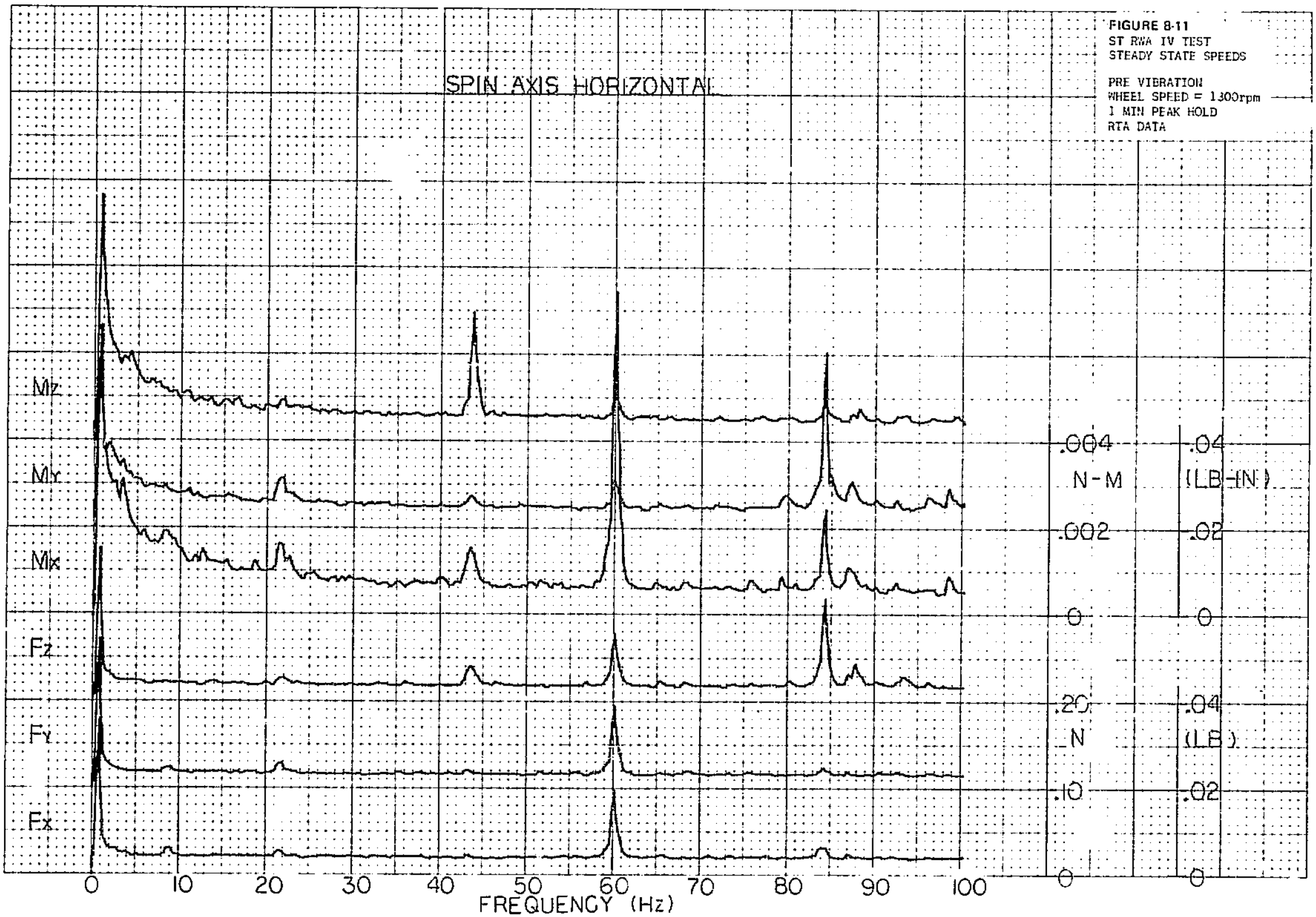


FIGURE 8-11
ST RWA IV TEST
STEADY STATE SPEEDS

PRE VIBRATION
WHEEL SPEED = 1300rpm
1 MIN PEAK HOLD
RTA DATA

31333

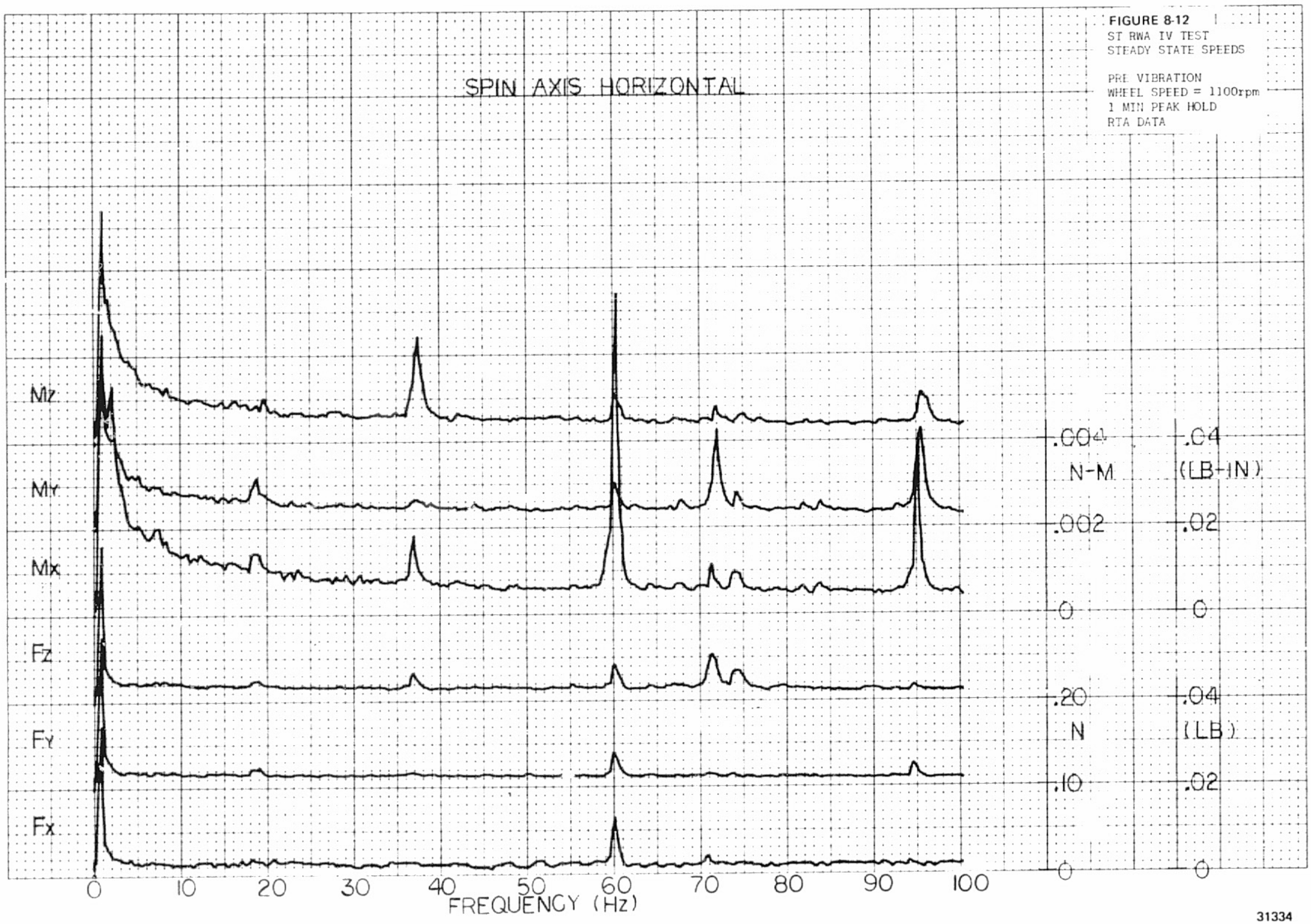
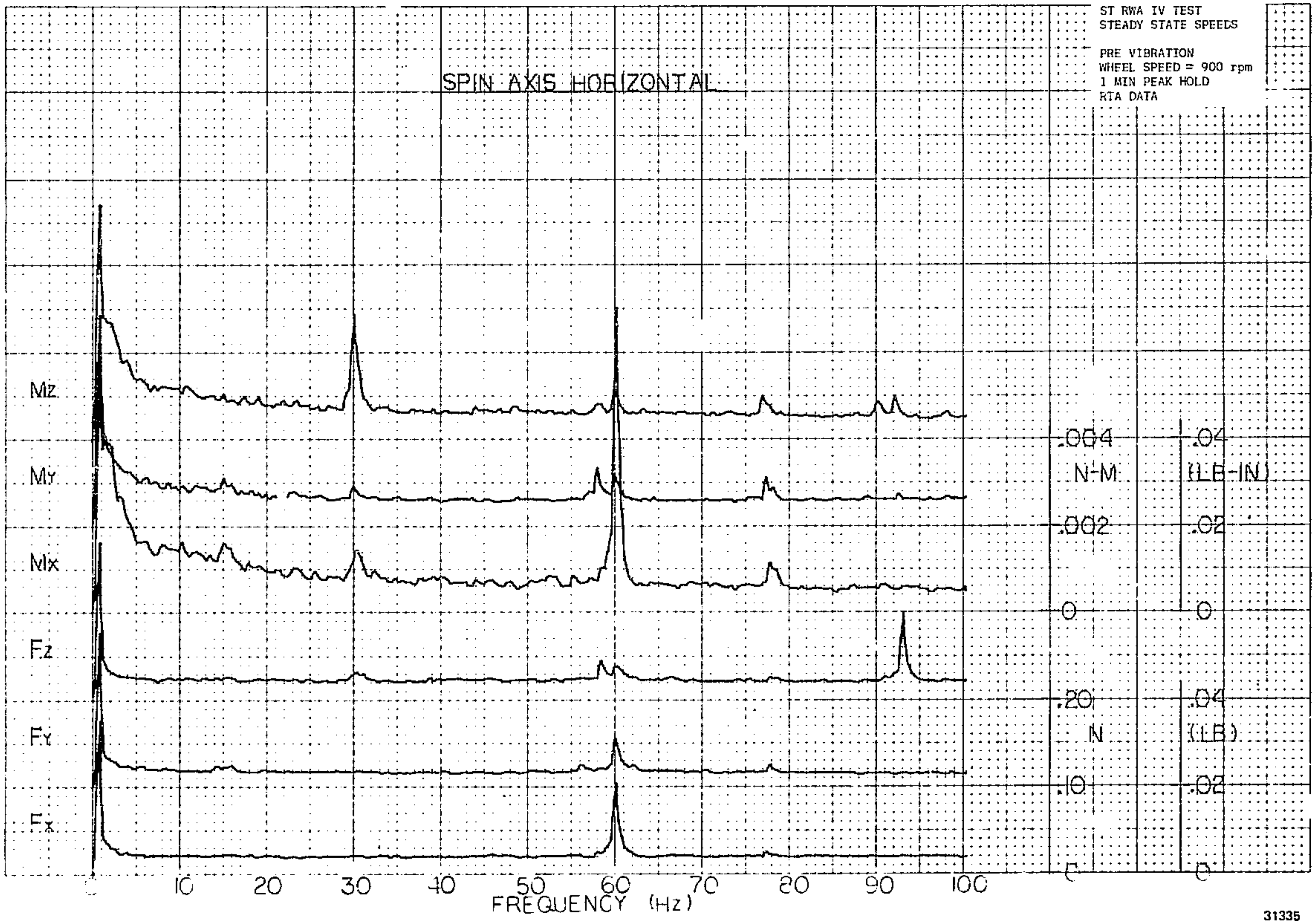


FIGURE 8-12
ST RWA IV TEST
STEADY STATE SPEEDS
PRE VIBRATION
WHEEL SPEED = 1100rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
31334

FIGURE 8-13
ST RWA IV TEST
STEADY STATE SPEEDS

PRE VIBRATION
WHEEL SPEED = 900 rpm
1 MIN PEAK HOLD
RTA DATA



31335

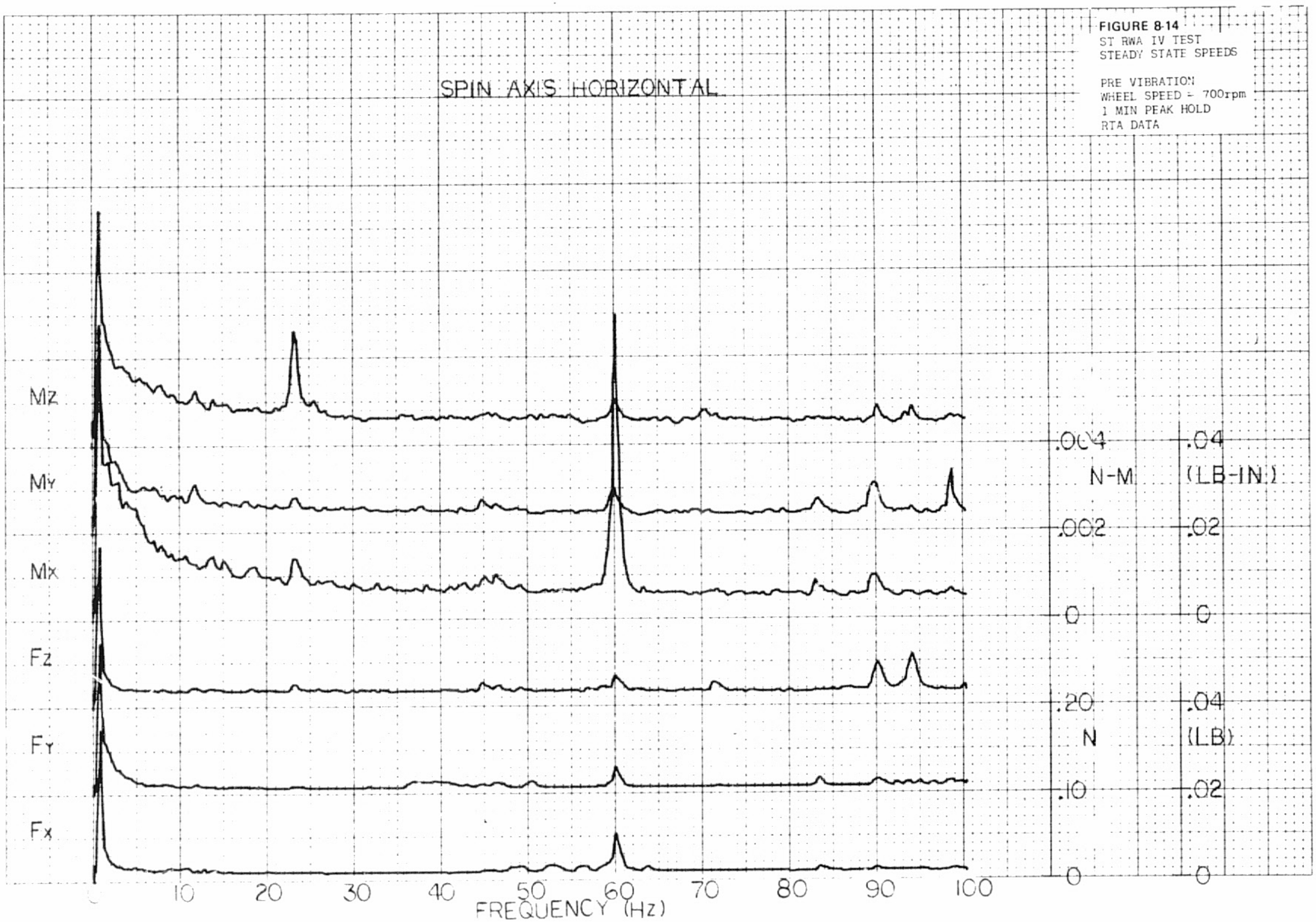


FIGURE 8-14
ST RWA IV TEST
STEADY STATE SPEEDS
PRE VIBRATION
WHEEL SPEED = 700rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
.002
0
N-M
.04
.02
0
(LB-IN)
.20
.10
0
N
.04
.02
0
(LB)
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31336

FIGURE 8-15
ST RWA IV TEST
STEADY STATE SPEEDS
PRE VIBRATION
WHEEL SPEED = 500rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
31337

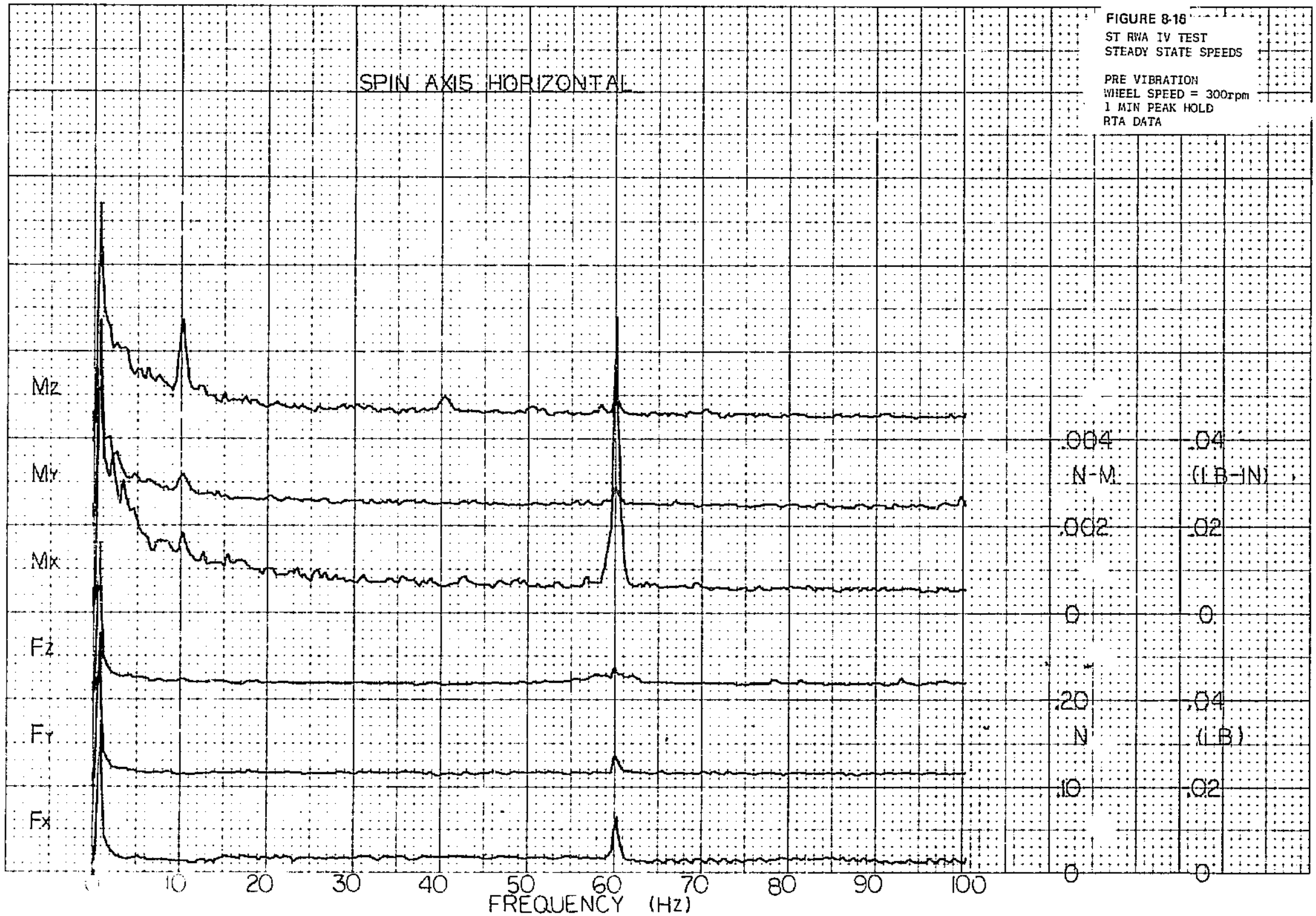


FIGURE 8-16
ST RWA IV TEST
STEADY STATE SPEEDS

PRE VIBRATION
WHEEL SPEED = 300rpm
1 MIN PEAK HOLD
RTA DATA

31338

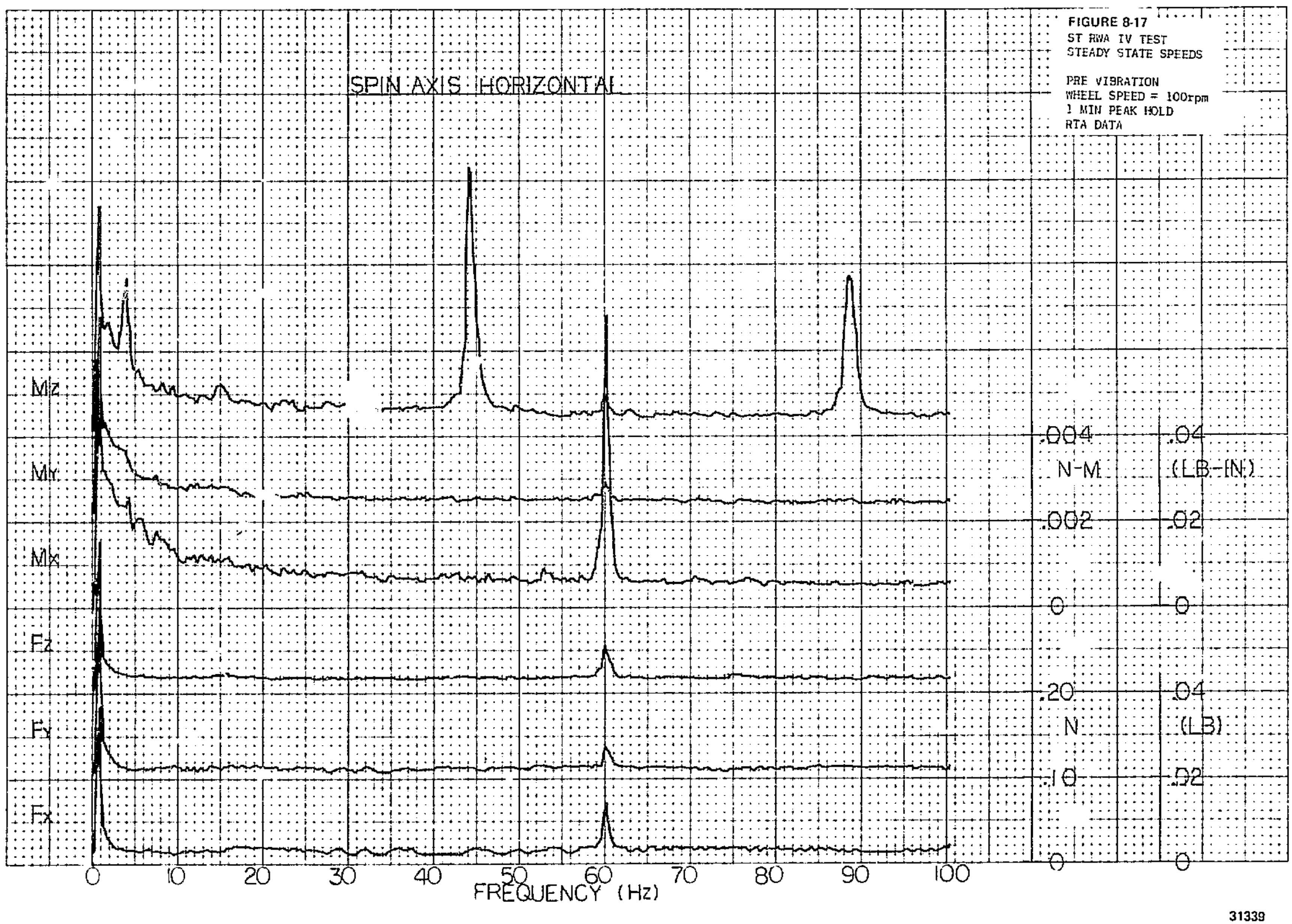


FIGURE 8-17
ST RWA IV TEST
STEADY STATE SPEEDS
PRE VIBRATION
WHEEL SPEED = 100rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
31339

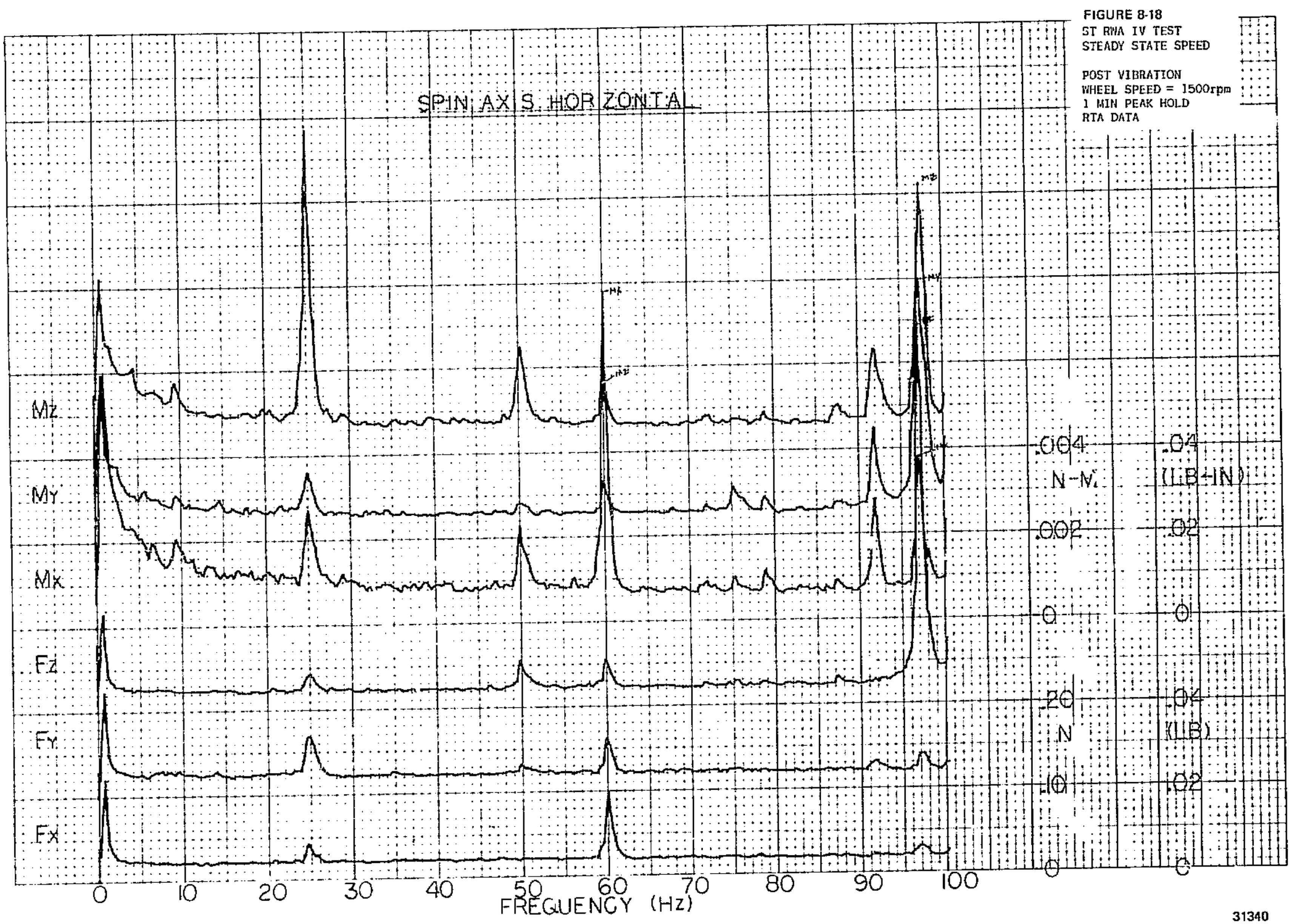


FIGURE 8-18
ST RWA IV TEST
STEADY STATE SPEED
POST VIBRATION
WHEEL SPEED = 1500rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31340

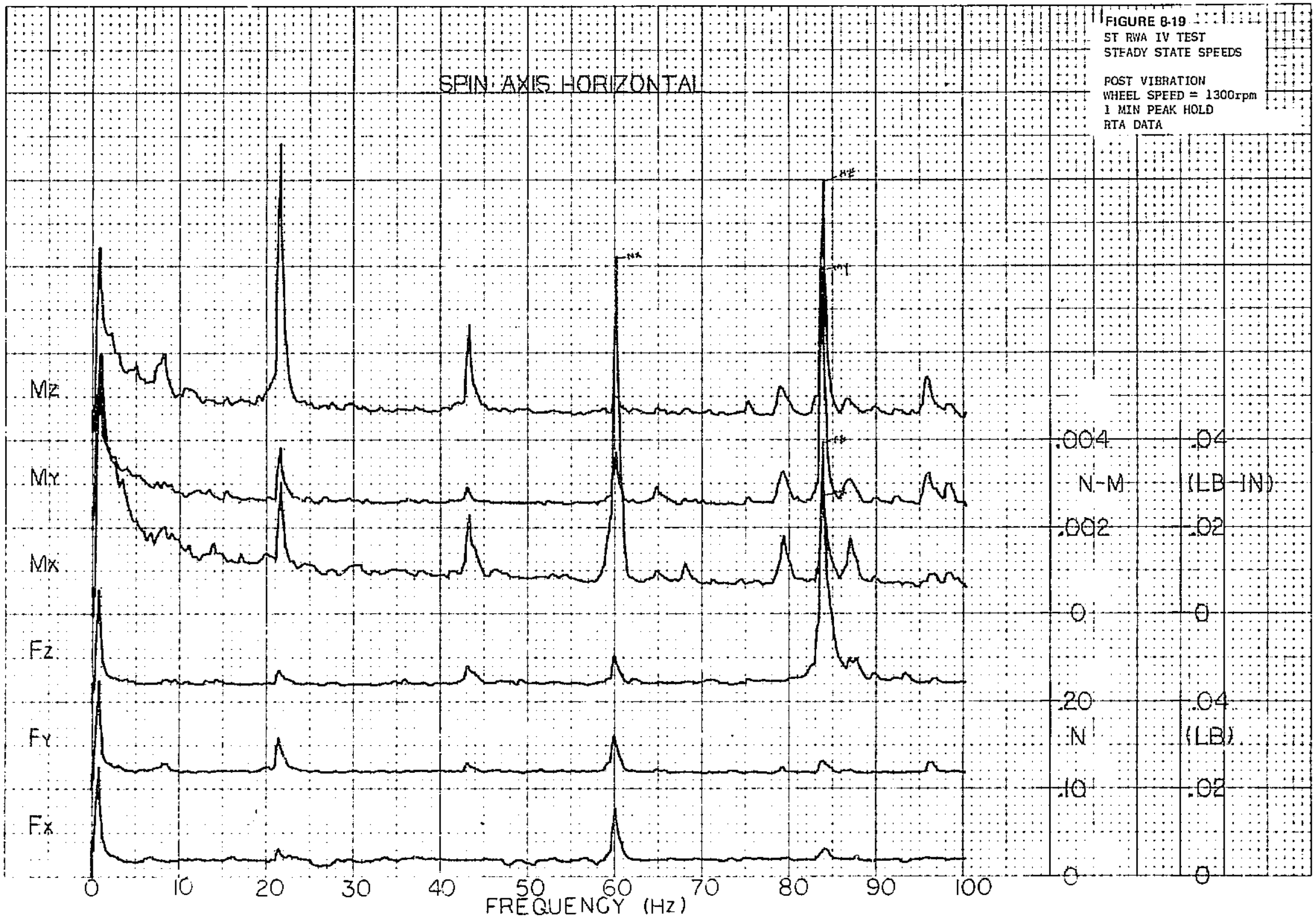


FIGURE 8-19
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 1300rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31341

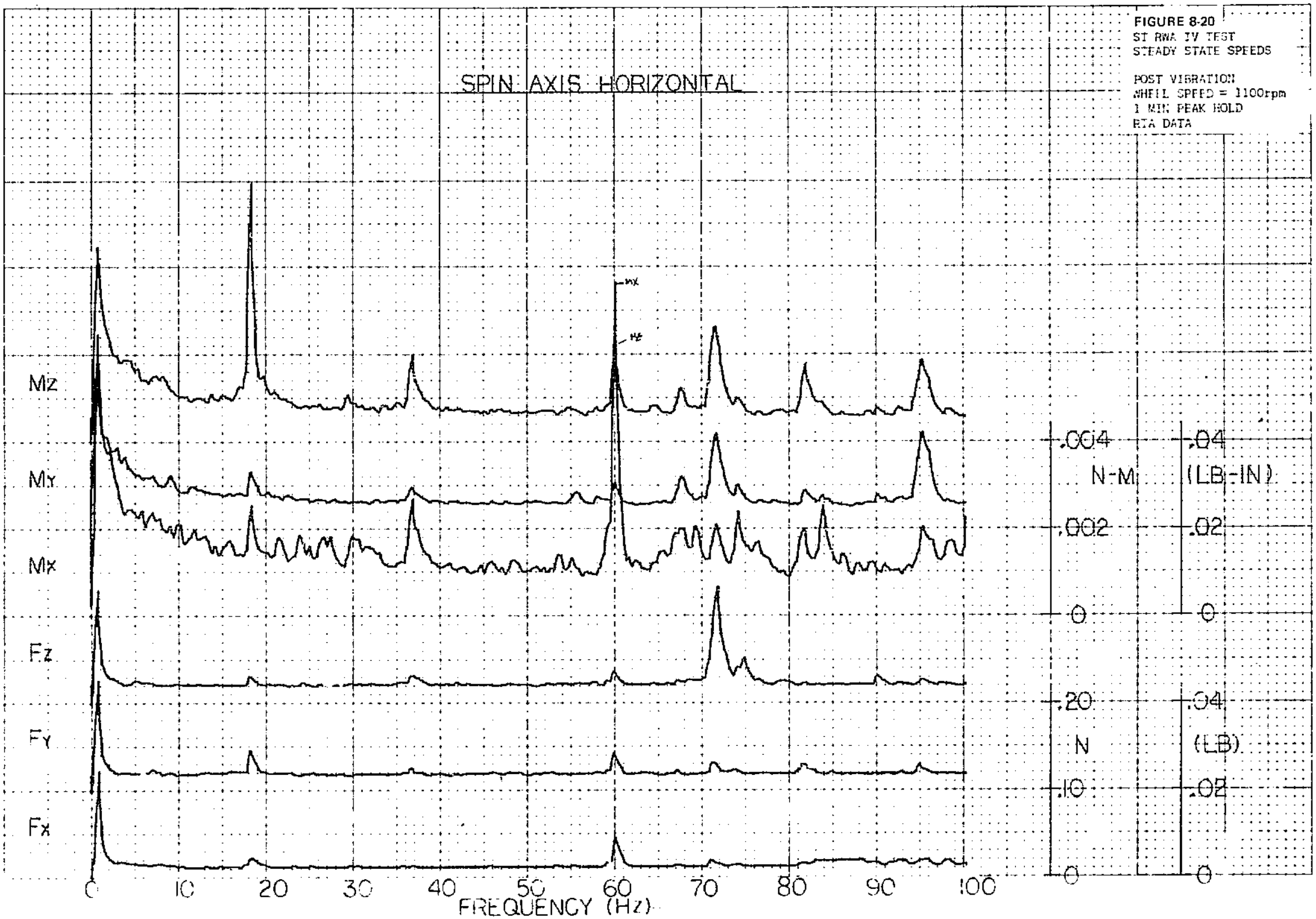


FIGURE 8-20
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 1100rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.04
(LB-IN)
.002
.02
0
.20
N
.04
(LB)
.10
.02
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31342

8-2

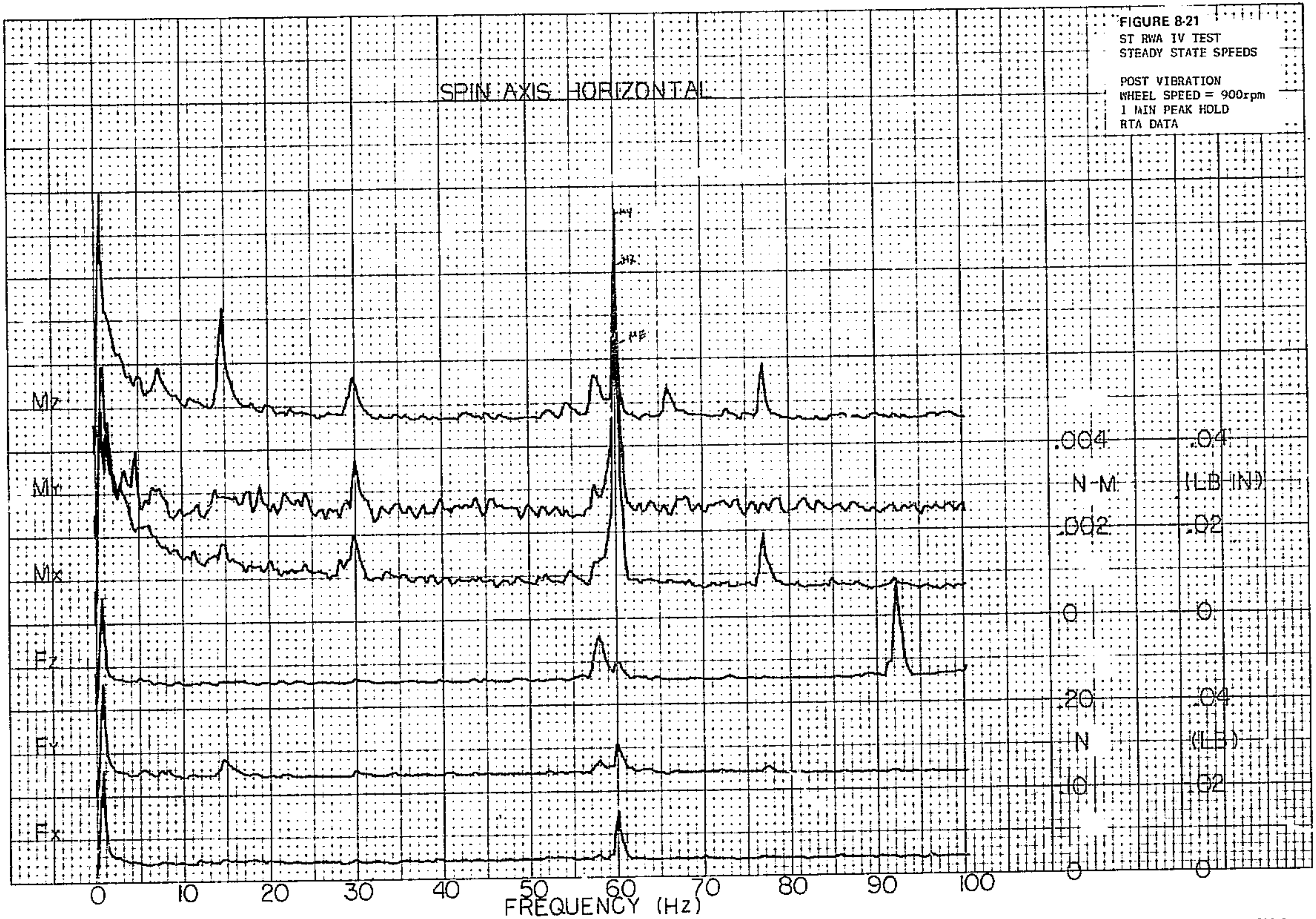
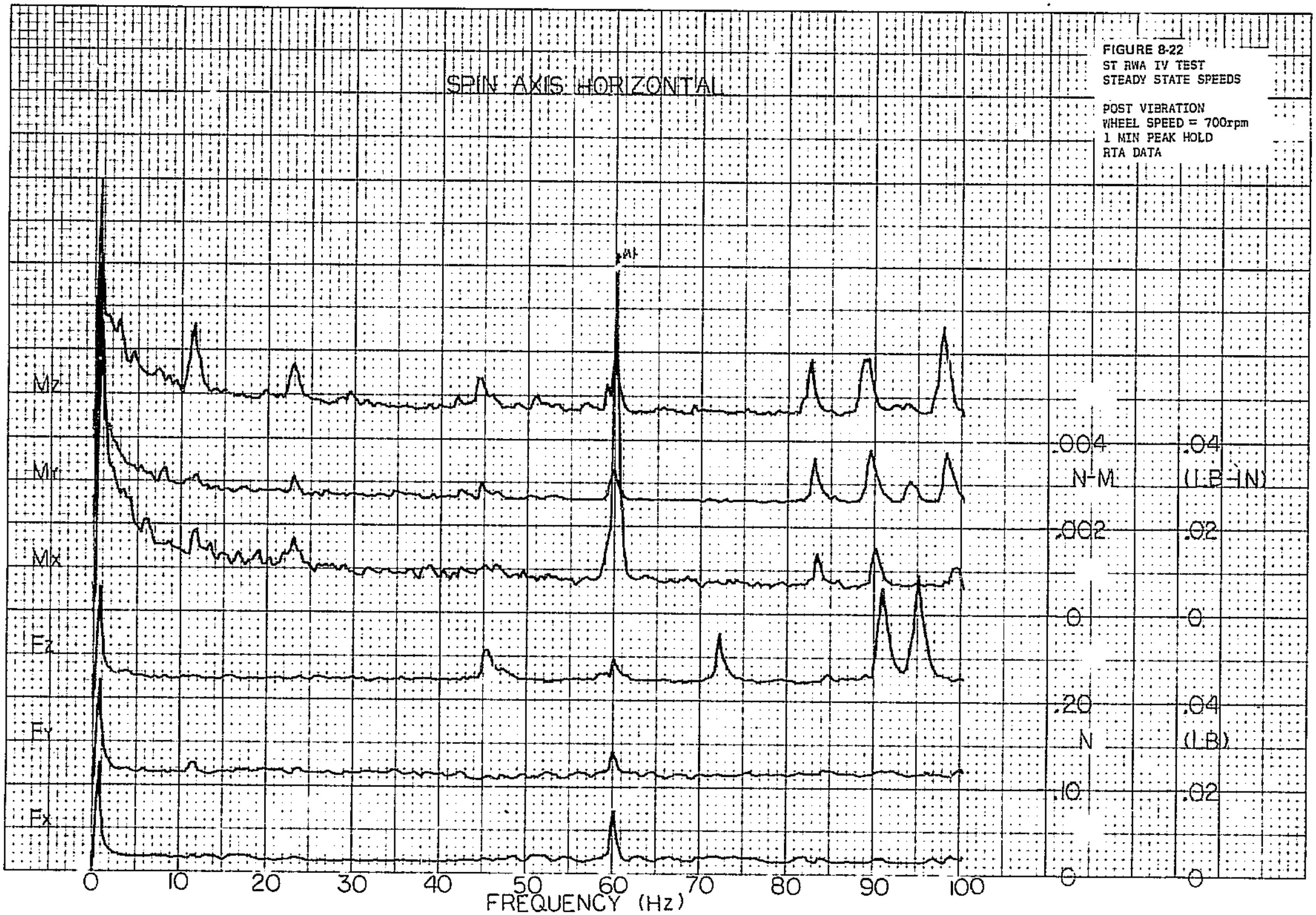


FIGURE 8-21
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 900rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31413


SPIN AXIS HORIZONTAL
FIGURE 8-22
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 700rpm
1 MIN PEAK HOLD
RTA DATA
Mz
My
Mx
Fz
Fy
Fx
.004
.04
N-M
(LB-IN)
.002
.02
0
0
.20
.04
N
(LB)
.10
.02
0
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31343

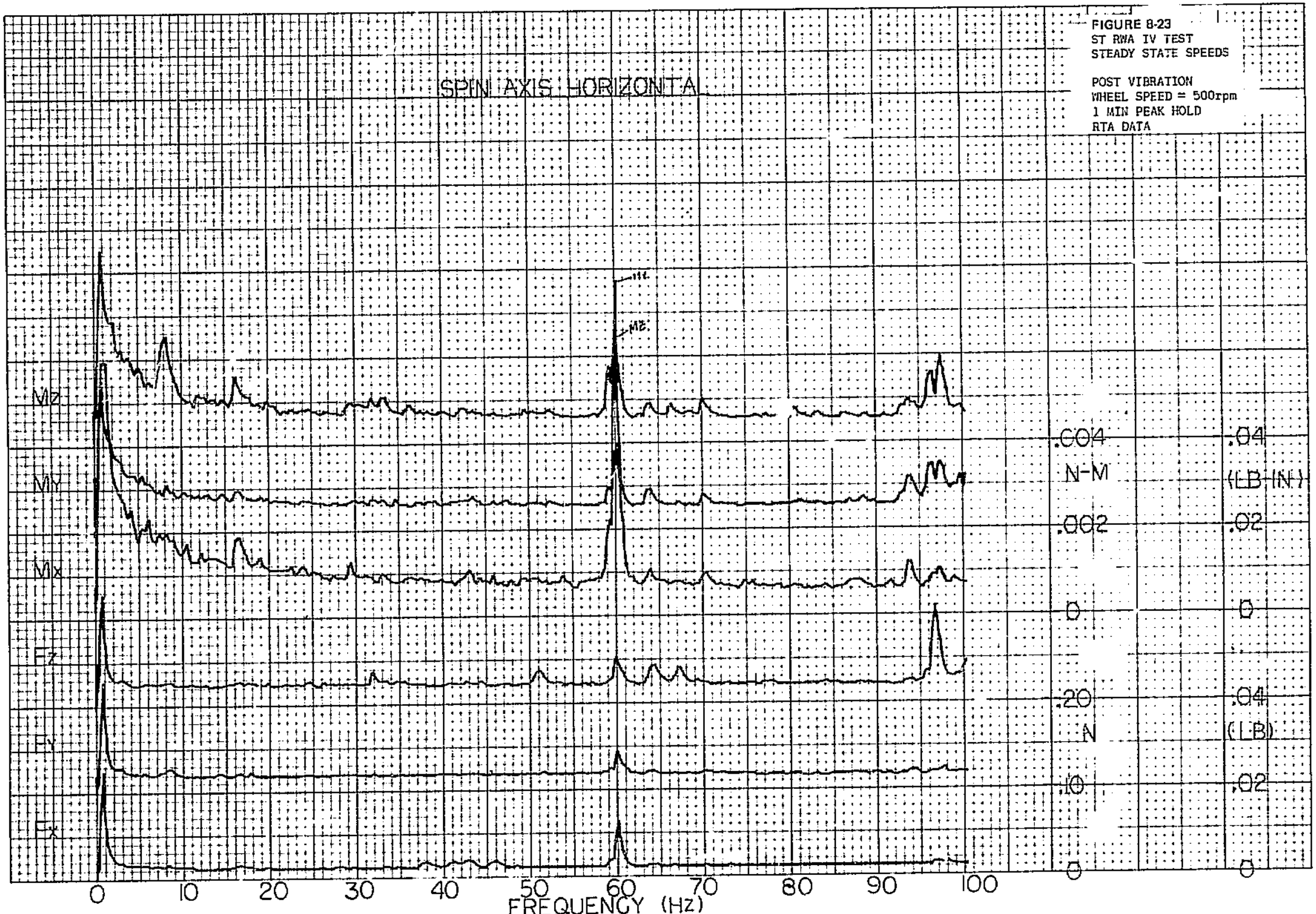


FIGURE 8-23
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 500rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31344

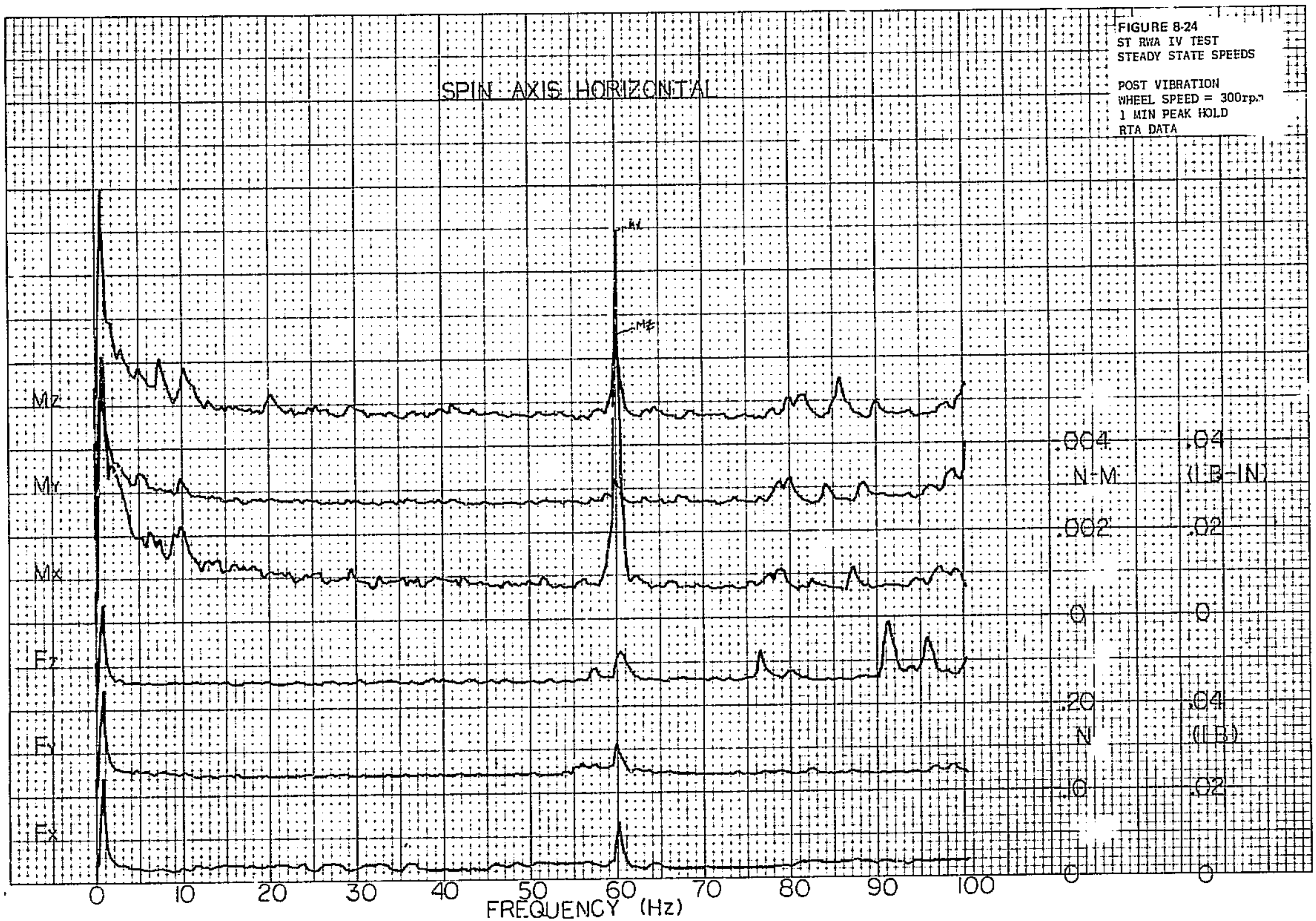


FIGURE 8-24
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 300rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
Mr
Mx
Fz
Fy
Fx
.004
N-M
.04
(LB-IN)
.002
.02
0
0
.20
N
.04
(LB)
.10
.02
0
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)

31345


FIGURE 8-25
ST RWA IV TEST
STEADY STATE SPEEDS
POST VIBRATION
WHEEL SPEED = 100rpm
1 MIN PEAK HOLD
RTA DATA
SPIN AXIS HORIZONTAL
Mz
My
Mx
Fz
Fy
Fx
.004
N-M
.002
0
.04
(LB-IN)
.02
0
.20
N
.10
0
.04
(LB)
.02
0
0
10
20
30
40
50
60
70
80
90
100
FREQUENCY (Hz)
31346

TABLE 8-1

SPACE TELESCOPE REACTION WHEEL SINE SEARCH RESONANCE DATA

Wheel Speed - Nonoperating

Sine Input Level - .25 grms from 5 Hz to 2000 Hz

Frequency Sweep Rate - 1 Minute per Octave

TABLE OF RESONANCE AMPLITUDES (Q)

	RESONANCE Frequency - (Hz)				
	75	200	260	350	600
(Spin) X Axis	1.65			25	
(Trunnion) Y Axis		3.7	11.4		4.3
	<u>Rotor Resonance</u> Actual Q to Rotor from Acc. Mount is 5/1 ∴ Q ≈ 10	Spin Motor Stator Rocking Mode	Rotor Rocking Mode	Spin Motor Stator Undamped Response	Fixture Mounting Interface Compliance

TABLE 8-2

SPACE TELESCOPE REACTION WHEEL EMITTED VIBRATION DATA

Wheel Speed = 1500 rpm (25 Hz)

M_x, M_y, M_z moments in N-m (lb-in.)

F_x, F_y, F_z Forces in N (lb)

	25 Hz EV Amplitudes					
Test Conditions	M_x	M_y	M_z	F_x	F_y	F_z
Previbration Baseline	.0014 (.0124)	.0007 (.0059)	.0002 (.0015)	.0071 (.0016)	.0107 (.0024)	.0089 (.0020)
After 3 Axes Random Vibration at 6.5 g_{avg}	.0018 (.1060)	.0008 (.0071)	.0070 (.0618)	.0165 (.0037)	.0431 (.0097)	.0169 (.0038)

SECTION 9.0

BEARING DRAG TORQUE

SECTION 9.0

BEARING DRAG TORQUE

Throughout the testing program the drag torque of the ST RWA was monitored to determine any change to bearing performance resulting from the environmental exposures. Housing internal pressure is normally maintained at $< 10^{-3}$ torr. This data was taken by removing spin motor power to the ST RWA rotor operating at 1500 rpm and recording the coasting speeds every minute for a 5 minute period. The five data points were averaged and applied to the drag torque formula determined as follows:

$$T_D = \frac{I\omega(\ 1 - \omega 2)}{t}$$

$$T_D = \frac{2\pi I}{60t}(N_1 - N_2)$$

where

T_D = Drag Torque, N-cm (oz-in)

I = 39.73 N-cm-s^2 (56.26 oz-in-sec^2) rotor inertia as measured

= rotor angular velocity rad/sec

N = rotor angular velocity rpm

t = 60 seconds time of rotor speed change from state 1 to state 2

applying the known constants to the formula yields

$$T_D = \frac{2 \quad (39.73)}{60^2} \Delta N$$

$$T_D = (.0693) \quad \Delta N \text{ N-cm}$$

$$= (.0982) \quad \Delta N \text{ (oz-in.)}$$

where

N = average rpm change for 1 minute

The results are tabulated in Table 9-2 for the various test conditions performed.

TABLE 9-2

ST RWA DRAG TORQUE DATA

Test Condition	ΔN (rpm)	T_{Drag} (oz-in.)	T_{Drag} (N - cm)
Initial Baseline (RT)	15.6	1.53	1.08
At 30°F (0°C)	19.8	1.94	1.37
Post 30°F Check (RT)	17.6	1.73	1.22
Post 140°F (50°C) Storage For 16 hr (RT)	17.2	1.69	1.19
After 3 Axes Random (RT) Vibration	25.6	2.51	1.77
After -30°F (-35°C) (RT) Storage for 16 hr	15.2	1.49	1.05

The increase noted after the random vibration exposure was due to the pressure level inside the housing being higher than 10^{-3} torr. The unit had been disassembled prior to random vibration exposure to check for proper lockwiring and time did not permit a proper pump-down period to remove all contaminants. Subsequent to the 1.77 N-cm (2.51 oz-in.) measurements, the unit was properly pumped to $<10^{-3}$ torr and drag torque dropped to 1.43 oz-in.

The 12 percent increase at low temperature is in the normal range for low temperature operation with the lubrication system used for these bearings. The variation in drag torques measured at room temperature, other than the past vibration measurement, are considered within typical measurement to measurement tolerances. The key point is that no significant change was experienced in bearing drag torque due to any of the environmental exposures.